M

Journal of Experimental Psychology

RECEIVED JUN 25 1953 THE JOHN CRERAR LIBRARY

ARTHUR W. MELTON, Editor
HUMAN RESOURCES RESEARCH CENTER
LACKLAND AIR FORCE BASE
SAN ANTONIO, TEXAS

CONSULTING EDITORS

Judson S. Brown, *State University of Iowa*
Cletus J. Burke, *Indiana University*
Robert M. Gagné, *Human Resources Research Center*
Frank A. Geldard, *University of Virginia*
James J. Gibson, *Cornell University*
Clarence H. Graham, *Columbia University*
David A. Grant, *University of Wisconsin*
Lloyd G. Humphreys, *Human Resources Research Center*
Donald B. Lindsley, *University of California, Los Angeles*
Neal E. Miller, *Yale University*
Edwin B. Newman, *Harvard University*
Kenneth W. Spence, *State University of Iowa*
Benton J. Underwood, *Northwestern University*
Delos D. Wickens, *Ohio State University*

Lorraine Bouthilet, Managing Editor

CONTENTS

Retinal Traces and Visual Perception of Movement: K. MOTOKAWA 369

The Physiological Mechanism of Apparent Movement: K. MOTOKAWA AND M. EBE 378

The Role of Stimulus Satiation in Spontaneous Alternation: M. GLANZER 387

Act Regression As a Special Case of Retroactive Inhibition and Functionally Related to Stimulus Generalization: E. SALTZ 394

Transfer of Predifferentiation Training in Simple and Multiple Shape Discrimination: M. D. ARNOULT 401

The Role of Irrelevant Drive Stimuli in Learning: S. LEVINE 410

Eyelid Conditioning As a Function of the CS-US Interval: W. R. MCALLISTER 417

The Effect on Eyelid Conditioning of Shifting the CS-US Interval: W. R. MCALLISTER 423

The Paintal Index As an Indicator of Skin-Resistance Changes to Emotional Stimuli: D. N. ELLIOTT AND E. G. SINGER 429

Anticipative Transfer of Mechanically Guided Turns: G. M. HASLERUD 431

Warm-up Effect in Human Maze Learning: C. E. HAMILTON AND W. R. MOLA 437

Satiation in a Reversible Perspective Figure: V. R. CARLSON 442

The Visibility of a Target As a Function of Its Speed of Movement: W. T. POLLOCK 449

American Psychological Association

Vol. 45 No. 6 June 1953

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

The JOURNAL OF EXPERIMENTAL PSYCHOLOGY is published monthly, two volumes per year, by the American Psychological Association, Inc. The subscription rate per volume is $7.50, or $15.00 annually. Single copies are $1.50. Subscriptions, orders, and business communications should be addressed to the American Psychological Association, Inc., 1333 Sixteenth St. N.W., Washington 6, D. C.

This JOURNAL publishes original experimental investigations which are intended to contribute toward the development of psychology as an experimental science. Studies with normal human subjects are favored over studies involving abnormal or animal subjects. Studies in applied experimental psychology or engineering psychology may be accepted if they have broad implications for experimental and theoretical psychology. Normally, articles of a length exceeding 15 printed pages cannot be accepted. However, an integrated series of studies accomplished simultaneously (e.g., most doctoral dissertations) must be presented in a single article, rather than in a series of articles.

Articles are published in the order of their receipt, except in rare circumstances. Authors who request them are supplied with 50 free offprints without covers. All of the cost of an author's alterations in galley proof is charged to the author, and one-half of the cost of tables, cuts, and formulas. Priority in publication is given to articles whose authors assume the full cost of publication.

Address all articles submitted for regular or priority publication to the editor, Arthur W. Melton, Human Resources Research Center, Lackland Air Force Base, San Antonio, Texas.

Manuscripts submitted to the JOURNAL *must* adhere to the conventions concerning reference citations, preparation of tables and figures, manuscript format, etc. as described in the Publication Manual of the American Psychological Association (*Psychol. Bull.*, 1952, 49 (4, Suppl.), 389–449. In particular, the organization of the manuscript should be text, references, footnotes, tables (one to a page), figure titles (typed on separate page), and figures. All typed material *must* be double-spaced with ample margins. The term "subject," with its various forms, is abbreviated *S*, *Ss*, *S*'s, and *Ss*'; analogous abbreviations are used for "experimenter" (*E*) and "observer" (*O*). When in doubt about the practices of the JOURNAL, authors should examine a recent issue.

Entered as second-class matter, February 6, 1937, at the post office at Lancaster, Pa., under the Act of March 3, 1879.

Acceptance for mailing at the special rate of postage provided for in paragraph (d-2), Section 34.40, P. L. & R. of 1948, authorized September 11, 1947.

Journal of
Experimental Psychology

VOL. 45, NO. 6 JUNE, 1953

RETINAL TRACES AND VISUAL PERCEPTION OF MOVEMENT

KOITI MOTOKAWA

Department of Physiology, Tohoku University

In physiological optics it is assumed that the perception of the size and form of an external object is determined by its optical image on the retina. However, many psychological phenomena such as optical illusions, perceptual constancies, etc. cannot be accounted for on the basis of such simple principles. Such phenomena, difficult to interpret in terms of physiological optics, have been ascribed to the function of the central nervous system and thus placed outside the pale of experimental researches, for it is difficult at the present stage of brain physiology to provide any physiological evidence for or against many hypotheses advocated by psychologists.

As is well known, the retina is ontogenetically a part of the brain, and its structure resembles that of the central nervous system (15). It is therefore not surprising that psychological phenomena such as optical illusions should be interpreted in terms of retinal processes. In a previous paper (9) I mapped out fields of retinal induction around optical images of various figures by means of a physiological method described in another paper (7) and found that the fields of retinal induction were distinctively patterned by the figure involved. The suggestion was made that the experience of illusion may perhaps be accounted for by deformations in the fields of retinal induction.

As the apparent size of an external object is not always proportional to the size of its retinal image, so is the apparent velocity of a moving object not always in proportion to its retinal velocity. If the field of retinal induction has some effect upon the perception of form and size, as suggested in the previous paper, it is to be expected that the field of retinal induction has also some effect upon the perception of velocity. In the present investigation experimental evidence for this idea has been provided.

METHOD

The method is described in detail in previous papers (7, 8, 9, 11), so that only the principle of the method and some remarks on the procedure for determination of electrical thresholds of the eye will be mentioned here. Following a brief illumination, the electrical sensitivity of the dark-adapted eye as measured with electrical phosphenes as an index increases above normal after a brief depression, reaches a maximum in a few seconds and decreases gradually to the resting level. The effect of light can be measured quantitatively by the amount of increase in elec-

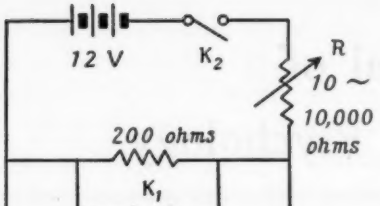

FIG. 1. Circuit used for electrical stimulation of the eye. K_1 and K_2 are opened in succession by means of a spring rheotome at an interval of 100 msec.

trical sensitivity. The quantity is defined by the formula:

$$\zeta = 100\,(E - E_o)/E_o,$$

where E and E_o represent excitabilities with and without preillumination. The crest time of a ζ-time curve is different according to the wave length of the light used for preillumination, but never depends on its intensity. In people with normal vision the crest time is about 1, 1.5, 2, and 3 sec. for red, yellow, green, and blue lights, respectively. The maximal value of ζ increases in proportion to the logarithm of the intensity of the preilluminating light over a wide range.

There are a number of receptor systems having their own electrical thresholds in the retina, and this situation makes it difficult for beginners to obtain consistent data. As the applied stimulating voltage is reduced step by step, the intensity of electrical phosphenes decreases not always steadily; it occurs very often that at a certain voltage it becomes very difficult or almost impossible for untrained *O*s to discriminate electrical phosphenes from the background activity of intrinsic light of the retina and easier again on further reduction of stimulating voltages. This is an apparent threshold presumably corresponding to the threshold of a less sensitive receptor system. The "true threshold" is attained after having passed a few such apparent thresholds. Trained *O*s can easily pass apparent thresholds and reach the true threshold, but untrained *O*s stop at one of the apparent thresholds, because they cannot discriminate sufficiently slight phosphenes from the background.

When E is not aware of this situation, he takes one of apparent thresholds for a true one, and, to make the matter worse, he can reject the method as inapplicable, because he misunderstands that great discrepancies which might be observed among the data obtained under the same experimental conditions would be due to experimental errors. In untrained *O*s the reliability of experiments cannot be raised by taking an average of data, which can belong to different populations. It is, therefore, necessary to carry out experiments only on trained *O*s or to endeavor to measure true thresholds with special precautions, if *O*s are untrained.

The stimulating current used is a constant-current pulse of 100-msec. duration, which is produced by means of a circuit shown in Fig. 1. The applied voltage is calculated by the formula: $\frac{12 \times 200}{R + 200}$ volts. An anticipatory stimulus, a click, is given .5 sec. prior to each electrical stimulus so as to make it easier to concentrate attention on the appearance of a phosphene. The variable resistance R is raised in steps from 500 or 1000 ohms until *O* feels difficulty in perceiving phosphenes. Then E gives alternately (*a*) the stimulus in question and (*b*) one far below the threshold in a randomized order and asks *O* to tell which is stronger. If the answer is correct, the resistance is further raised in steps of about 20 ohms until discrimination fails. In order

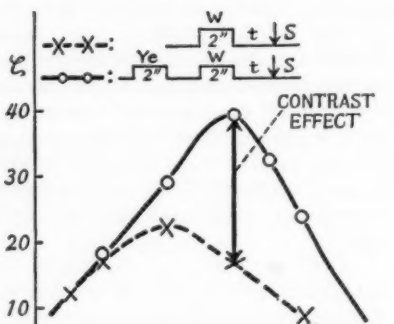

FIG. 2. Successive retinal induction. Solid curve: ζ-time curve for successive stimuli, yellow and white. Broken curve: ζ-time curve for white light alone. Temporal sequence of stimulation is shown in inset, where *Ye*, *W*, *S*, and *t* denote yellow light, white light, electrical stimulation, and interval between *W* and *S*, respectively.

that the value may be correlated with a true threshold, one must be sure that on raising the variable resistance further by about 100–200 ohms no perceptible phosphene appears again.

To determine one point, we repeat 20–40 trials of stimulation at an interval of 5–15 sec. The excitability at the resting level E_0 is determined each time except for cases in which E_0 remains stable. The values of E_0 successively determined should not vary more than 10%. Unsteadiness of E_0 is caused by sweating and fatigue of *Os*. Therefore the room should be kept cool and well ventilated, and a too long session avoided. In a session of about 2 hr., 5 to 10 points are determined, and one series of experiments is completed in a few sessions. Our *Os* are trained until they can reproduce ζ values within a difference of 2 in terms of ζ. Therefore a difference greater than 2 in ζ values is generally significant in our experiments. It takes a few months or so for such training. Fairly consistent results can, however, be obtained even from untrained *Os*, provided that *E* is well aware of the factors stated above and measures thresholds with due precautions.

Results

When the eye is exposed to yellow light and a few seconds later to white light, a ζ-time curve is obtained which has a maximum at about 3 sec. and is much higher than the curve for white light alone (see Fig. 2). Since a crest time of about 3 sec. is characteristic of a curve for blue light, the experiment mentioned above shows that successive stimuli, yellow and white, are equivalent to blue light. This phenomenon is a physiological correlate of successive color contrast. The difference between the two curves, such as is indicated in Fig. 2, serves as a measure for the intensity of induction and is called "contrast effect." This quantity depends on the intensity of inducing colored light, but little on the intensity of the white test-light. To measure contrast effects caused by yellow light one measures ζ values only at 3 sec.

When an optical image moves across the retina, an aftereffect remaining in the pathway can be measured by the method mentioned above. If the contrast effects along the pathway are represented as a function of distance along the path, we obtain a curve which will for simplicity be called a "trace-curve." Experimental arrangements for obtaining trace-curves were as follows: In the middle of a vertical screen standing in a dark room a rectangular opening 30 mm. wide and 10 mm. long was made and covered with a large plate of ground glass. Just behind the screen, a band of black paper containing a long vertical slit 2 mm. wide was moved at a constant rate by means of a kymograph. The slit was illuminated from behind by a sodium lamp,[1] so that *O* saw a vertical yellow line move from left to right at a constant velocity. The distance between the screen and the eye was usually 40 cm. The *O* fixated a very small red light placed a few centimeters below the opening. After the displacement of the figure across the retina is over, a white test-spot 2 mm. in diameter is presented at any point in the pathway for 2 sec., and electrical excitability is measured 3 sec. after the end of the white stimulus. The interval between the moving stimulus and the white test-stimulus has no effect on the results, but in our experiments it was fixed at 2 sec. The intensity of the white stimulus has also little influence upon contrast effects, but it was fixed at 40 lux in our experiments.

The ζ-time curves obtained from the pathway of the moving figure were always found to be of the same type as the curve shown in Fig. 2, but the magnitude of maximal ζ or the value at 3 sec. was found different from point to point in the pathway. In Fig. 3 trace-curves for three different objective velocities are illustrated. From

[1] A yellow filter may be used with no qualitative difference in results.

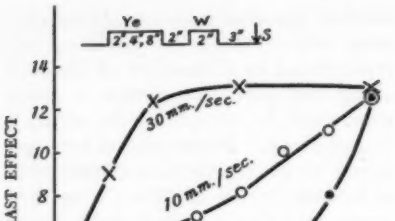

FIG. 3. Trace-curves for yellow vertical bars 10 × 2 mm. in size moving at different velocities. Notations in inset as in Fig. 2. Distance between eye and figure was 40 cm.

this figure the following properties of retinal traces can be observed: (*a*) The magnitude of contrast effects increases from the start toward the end of the path, giving rise to a gradient in the direction of motion. (*b*) The higher the objective velocity, the greater the initial gradient. (*c*) A trace-curve obtained at a higher velocity is higher except at the end of the path. (*d*) All trace-curves reach a final common height, irrespective of objective velocities. The data obtained from another *O* are shown in Table 1.

TABLE 1

EFFECT OF VELOCITY UPON RETINAL TRACE WITH MOVING OBJECT SIZE 5 × 2 MM. AND DISTANCE FROM EYE 30 CM.

Distance from Start in Mm.	Contrast Effects		
	v = 5 mm./sec.	*v* = 10 mm./sec.	*v* = 20 mm./sec.
1	1.5	1.5	1.0
5	2.0	5.5	6.5
10	2.5	7.0	11.0
15	6.0	9.0	10.0
20	10.0	—	12.0
24	13.0	11.0	11.0

According to Brown and others (**1, 2, 3, 4, 6**), a larger object appears to move more slowly when other experimental conditions are the same. If the retinal trace as measured by our method really contributes to the perception of movement, it would be expected that a trace-curve for a larger object would be lower and show a smaller initial gradient. In the following experiment vertical bars 5, 10, and 20 mm. in length and 2 mm. in width, were moved in the horizontal direction at a constant external velocity of 10 mm./sec. The result is shown in Fig. 4. In accordance with the psychological experience stated above, the trace-curve for the largest object lies at the bottom, that for the smallest at the top and that for the middle-sized one in an intermediate position. The initial gradients become greater as the sizes of the moving objects decrease.

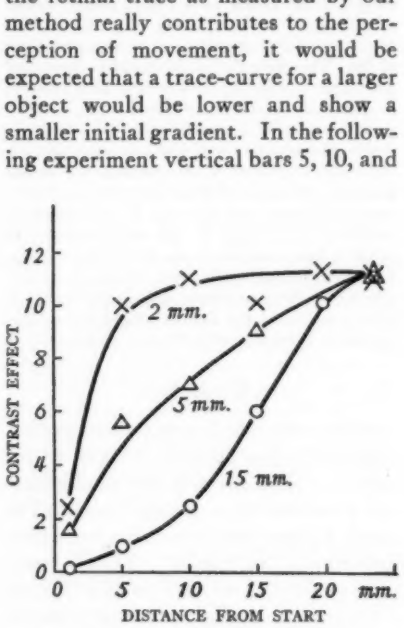

FIG. 4. Trace-curves for vertical bars of varying lengths: velocity 10 mm./sec., distance from eye 30 cm.

In the next series of experiments, the orientation of a bar 10 mm. long

and 2 mm. wide was varied. The result is shown in Fig. 5. As can be seen in this figure, the trace-curve for the horizontal bar is decidedly higher than that for the vertical. This finding also corresponds to the well-known psychological experience that an object oriented in the direction of motion appears to move faster than one at right angles to it. Next, the moving field or the diaphragm aperture together with the moving figure was made exactly one-half the size of that used above; the aperture was now 15 mm. wide and the figure 5 × 1 mm., but the velocity remained the same. The trace-curve thus obtained was found to be much higher than the control curve and even higher than the curve obtained in the experiment in which the figure alone was reduced in size.

The psychological law established by Brown states: If in a homogeneous field one transposes a moving field in all its linear dimensions, one must transpose the stimulus velocity by a like amount in order that phenomenal identity of velocity results. In order to make the apparent velocity of our reduced figure almost identical to the perceived velocity of the original one,

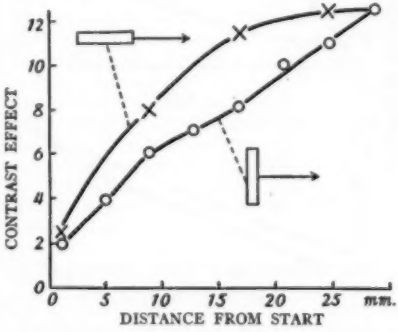

FIG. 5. Trace-curves for bars oriented in direction of motion and at right angles to it: velocity 10 mm./sec., distance from eye 40 cm.

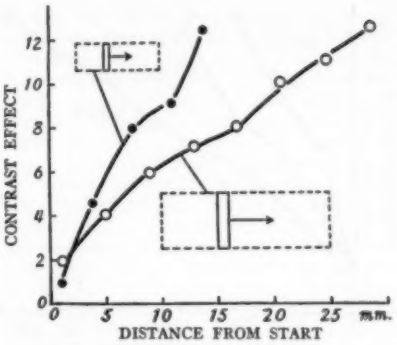

FIG. 6. Effect of parallel reduction of size and velocity upon gradient of retinal trace. Curve marked by empty circles is control.

the objective velocity was now reduced to one-half. At first I expected that the trace-curve obtained under such conditions would approximately coincide with the original one, because identical trace-curves would correspond to identical phenomenal velocities. In reality, however, the initial gradient of the trace-curve was found to be far greater than in the original one, as can be seen in Fig. 6. This experiment indicates that the retinal trace is not the only factor determining the apparent velocity. For this reason we should probably do well to consider that the chief determinant of apparent movement is the retinal velocity itself, the retinal trace being an accessory that modifies what is determined by the retinal velocity. In the above-mentioned experiment the velocity was reduced to one-half, so that the retinal velocity must have been reduced to the same rate. This loss of retinal velocity must then have been compensated for by the increase in the initial gradient of trace-curve, so that the apparent velocity could remain constant.

Such an interpretation receives further support from the following experiment. With the other conditions

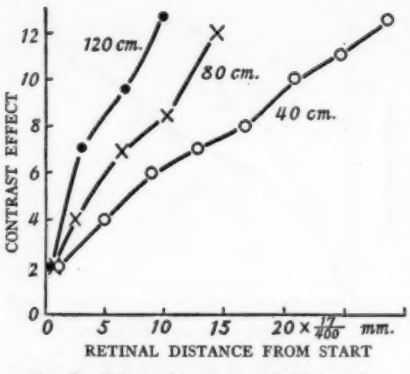

FIG. 7. Effect of variation of distance from eye (40, 80, 120 cm.) upon gradient of retinal trace.

constant, the distance from the eye was made twice or three times as large as in the original experiment. It is apparent that the retinal velocity was thus reduced to one-half or one-third. The result is shown in Fig. 7, which indicates that the greater the distance from the eye, the greater the initial gradient of the trace-curve. Such changes would compensate for the loss of retinal velocity, so that the apparent velocity can be held constant in spite of changes in retinal velocity. In this manner the problem of perceptual constancy seems to give a clue to physiological interpretation.

From what has been said it may be inferred that the apparent velocity is determined by the retinal velocity when the retinal trace is held constant. However, to hold the latter constant is so difficult a task that it is hardly possible to verify the notion, but the effect of retinal traces can be eliminated by providing a field of retinal induction common to two moving objects that are to be compared with each other. The following experiment will serve to demonstrate this relation. A vertical bar 15 mm. long and 2 mm. wide was moved in the horizontal direction at a constant rate of 10 mm./sec., and the trace-curve marked by dots in Fig. 8*A* was obtained. The curve marked by crosses in the same figure was obtained with a square 2 × 2 mm. in size under otherwise the same experimental conditions. The remarkable difference between the two curves is obviously based on the difference in size of the moving figures. Next, the two figures presented one above the other and 5 mm. apart were moved at the same time in the common visual field at the same velocity, and a retinal trace for each figure was measured along the horizontal line passing through the middle point of each figure. The trace-curves thus obtained show a striking resemblance to one another, as can be seen in Fig. 8*B*.

The figures appeared remarkably different in velocity, when observed separately, but the perceived velocity of both figures was, of course, identical in the simultaneous observation. Corresponding to this psychological

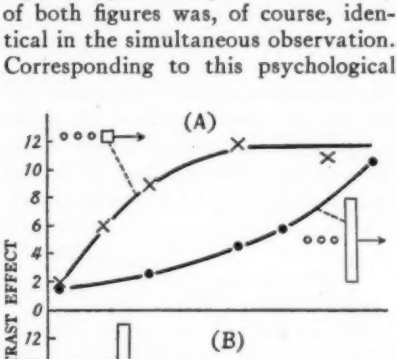

FIG. 8. Trace-curves for moving objects of different sizes (*A*) in separate observation, (*B*) in simultaneous observation: velocity 10 mm./sec., distance from eye 40 cm.

experience, the trace-curves exhibited a remarkable difference in one case, and a close resemblance in the other. As has been stated above, a retinal field common to both figures must have been established in this case because of their close proximity. The same situation must also be responsible for the known psychological fact that optical illusions of form and size decrease in magnitude or disappear completely when a comparison figure is brought near the "illusory" figure.

Discussion

There seems to be little doubt that retinal traces are important factors in the perception of real movement. It is now needed to elucidate the physiological mechanism of retinal traces.

As to the formation of gradients in the direction of motion, there seem, conceptually, to be at least three possibilities.

Hypothesis of spontaneous dissipation.—It is known that retinal induction decays spontaneously. If the retinal induction that is established latest disappears latest, the intensity of induction remaining along the pathway of a moving object must be found stronger toward the end of the path. This interpretation, however, contradicts the experimental fact that trace-curves depend little on the interval between the preceding colored and the subsequent white light. It was shown in the previous paper (7) that retinal induction remains unchanged for about 20 sec.; it takes 40–50 sec. for its complete dissipation. Therefore it is unlikely that the observed gradient could be produced by a temporally uneven dissipation of induction.

Hypothesis of summation.—It is known that the effect of a strong illumination spreads outside the geometrical image in the retina (irradiation). When a retinal area ahead of a moving stimulus is excited first by irradiation and then by the stimulus arriving at the area in question, summation of responses will result. The effect of irradiation will increase as the stimulus proceeds, because the effect originating in each point of the retinal pathway will, to some extent, be integrated. In this manner a gradient can be produced.

From this hypothesis it is to be expected that a greater figure would cause a greater gradient because the effects of integrated irradiation would be greater. As a matter of fact, however, a trace-curve for a greater figure shows a smaller initial gradient (Fig. 4). The hypothesis also cannot account for the result of the experiment performed with figures variously oriented. As shown above, all trace-curves have a final common height, and the value of contrast effect at this point is found equal to the value obtained with a standing figure. With a standing figure, there occurs no such overlap of stimuli as is assumed in the hypothesis. Hence no summation will take place. Nevertheless the value for a stationary stimulus is generally higher than any value in the retinal trace. This situation suggests that gradients of retinal traces are not caused by summation, but by some kind of suppression.

Hypothesis of retrograde suppression.—As mentioned above, retinal induction caused by any colored light, say yellow light, persists for 20 sec. or longer, but disappears at once when a remote region of the retina is subsequently exposed to a second yellow light. This phenomenon is called *neutralization of retinal induction* (10). The mechanism of this phenomenon is such that a complementary induction is set up by the second stimulus and propagated into a remote region to neutralize the induction caused by the first stimulus. This phenomenon, however, does not take place when the interval between two stimuli is too short, e.g., within .05 sec. As the interval increases, the induction caused by the first stimulus becomes more liable to the neutralizing effect of the second.

Let us suppose a similar interaction to take place between a moving stimulus and the retinal trace behind it. The trace is constantly subject to suppression exerted by induction spreading backward from the moving image, where the part of the trace produced earlier is more liable to this action, because the trace becomes more unstable with the lapse of time. In this way a gradient is established, and at the end of the path the highest value is reached which is equal to the value for a stationary stimulus, because there is no retrograde suppression there. From this hypothesis all the properties of retinal traces can be explained very clearly. For example, a lower trace-curve with a smaller initial gradient for a lower velocity may be ascribed to longer exposure to retrograde suppression (Fig. 3). A larger figure can set up a larger amount of spreading induction which has a stronger suppression upon the retinal trace, so that a lower trace-curve with a smaller initial gradient is obtained (Fig. 4). The major part of retrograde induction may be considered to come from the caudal contour of a moving figure. In a vertical line moving in the horizontal direction the effective

contour is longer than in a horizontal line moving in the same direction. In consequence, retrograde suppression is stronger in the former than in the latter, so that a lower trace-curve is obtained with the vertical line (Fig. 5).

In this manner the known psychological law of apparent velocity can be accounted for in terms of physiological properties of retinal induction. In spite of this, I do not claim that the perception of movement would be determined solely by peripheral events. There is no doubt that the central nervous system plays an important role in this function, although nothing more than speculations can be made concerning the central mechanism of apparent velocity at present. There are, however, a number of evidences for the peripheral nature of our phenomenon. For instance, retinal induction of quite the same qualities as in man has been proved in excised eyes of frogs with action-potentials of the optic nerve as the index (13), and also in mammalian eyes, when spike-potentials are picked up by a microelectrode inserted into the eyebulb as the index (14). Physiologists such as Granit (5), Talbot (16), and Thomson (17) are of the opinion that what is stimulated by electrical currents is neural network of the retina. Retinal induction is presumably a physiological state prevailing in synaptic membranes of the network.

Recent studies on the perception of motion have centered about stroboscopic movement. We report elsewhere (12) that a similar gradient is established in the field of stroboscopic movement. Therefore the idea outlined in the present paper may be in harmony with psychological data on apparent movement.

Summary

A physiological aftereffect of a moving retinal image was investigated by the method of electrostimulation. Aftereffects at a series of points in the retinal pathway were measured and plotted against distances. A curve thus obtained is called a "trace-curve."

1. The trace-curve increases in height with increases in distance from the start, giving rise to a gradient in the direction of motion.

2. The higher the velocity, the higher the trace-curve, and its initial gradient is greater.

3. A trace-curve for a large figure is low and its initial gradient is small. This finding corresponds to the psychological fact that a greater figure seems to move more slowly.

4. A trace-curve for a horizontal line moving in the horizontal direction is higher than that for the one oriented at right angles to it. This finding, too, is in good agreement with psychological experience.

5. The apparent velocity is little changed by reducing the linear dimensions of the moving field and the objective velocity to one-half of the original ones, but the retinal gradient becomes steeper. This finding may be interpreted to say that the retinal trace compensates for the loss of retinal velocity to keep the apparent velocity constant.

6. The physiological mechanism of retinal traces is discussed in terms of the known properties of retinal induction.

(Received October 7, 1952)

References

1. Brown, J. F. Ueber gesehene Geschwindigkeiten. *Psychol. Forsch.*, 1927, **10**, 84–101.
2. Brown, J. F. The visual perception of velocity. *Psychol. Forsch.*, 1931, **14**, 233–248.
3. Cartwright, D. On visual speed. *Psychol. Forsch.*, 1938, **22**, 320–332.
4. Graham, C. H. Visual perception. In S. S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley, 1951.
5. Granit, R. The organization of the vertebrate retinal elements. *Ergeb. Physiol.*, 1950, **46**, 31–70.
6. Koffka, K. *Principles of gestalt psychology*. New York: Harcourt, Brace, 1935.
7. Motokawa, K. Physiological induction in human retina as basis of color and brightness contrast. *J. Neurophysiol.*, 1949, **12**, 475–488.
8. Motokawa, K. Retinal processes and their role in color vision. *J. Neurophysiol.*, 1949, **12**, 291–303.
9. Motokawa, K. Field of retinal induction and optical illusion. *J. Neurophysiol.*, 1950, **13**, 413–426.
10. Motokawa, K. Propagation of retinal induction. *J. Neurophysiol.*, 1951, **14**, 339–351.

11. Motokawa, K. Some remarks on measurements of electrical excitability of the human eye. *Tohoku J. exp. Med.*, 1951, **54**, 385–391.
12. Motokawa, K., & Ebe, M. The physiological mechanism of apparent movement. *J. exp. Psychol.*, 1953, **45**, 378–386.
13. Motokawa, K., & Iwama, K. Color processes and physiological induction in frog's retina. *Tohoku J. exp. Med.*, 1951, **53**, 341–349.
14. Motokawa, K., Iwama, K., & Ebe, M. Retinal color processes in cats. *Jap. J. Physiol.*, 1952, **2**, 198–207.
15. Polyak, S. L. *The retina.* Chicago: Univer. Chicago Press, 1941.
16. Talbot, S. A. Recent concepts of retinal color mechanism. *J. opt. Soc. Amer.*, 1951, **41**, 895–941.
17. Thomson, L. C. A review of ideas on colour perception. *Ophthalm. Literature*, 1952, **6**, 3–40.

Journal of Experimental Psychology
Vol. 45, No. 6, 1953

THE PHYSIOLOGICAL MECHANISM OF APPARENT MOVEMENT

K. MOTOKAWA AND M. EBE

Department of Physiology, Tohoku University

It was shown by Motokawa (11) that a gradient of retinal induction is produced in a pathway of a stimulus moving across the retina, and that the direction and apparent velocity of motion depend on the direction and magnitude of the gradient. In view of the fact that the phenomena of apparent movement present fundamental problems concerning the perception of movement, it was attempted in the present investigation to study retinal induction caused by *stroboscopic* stimuli and to see whether a similar gradient is produced in the field of induction set up by such stimuli.

Procedure and Results

The method employed was essentially the same as that used in the preceding paper (11); and so only those modifications specifically required by the present experiments are described together with the results.

Conversion of retinal induction.—Before entering the discussion, a new phenomenon designated "conversion of retinal induction" will be mentioned in some detail, for this phenomenon represents a basic retinal process concerned not only with apparent movement, but also with the phenomenon of "subjective color" and the fusion of flicker. By the term "conversion" is meant the fact that retinal induction caused by a stimulus is changed in character by the action of a subsequent stimulus.

It is a well-known fact that color sensations can be produced by intermittent white light. We (12) investigated this phenomenon by means of the method of electrostimulation and found that color processes are elicited by two flashes of white light in the retina, when they are presented at an adequate interval. The color effect of successive stimuli can be demonstrated most clearly, based on the principle of retinal induction. This method is especially suitable to detect the effect of any unsaturated color. For example, when a white test-light is preceded by any light of unsaturated color—say yellowish-white light—a ζ-time curve is obtained which is much higher than the curve for white light alone and has a maximum at about 3 sec. (successive color induction). A similar striking difference in shape and height is found between a ζ-time curve for the white test-light preceded by two successive flashes of white light and the curve for the white test-light alone. This fact indicates that the preceding flashes of white light had a color-inducing effect.

The sort of color induced can be identified in three ways. The simplest method consists in comparing the shape of the ζ-time curve in question with the shape of those for spectral lights. The other methods will be explained by examples. In the upper diagram of Fig. 1, response curves for an equal-energy spectrum are illustrated. In these curves, data of electrical excitability at 1, 2, and 3 sec. after illumination are denoted by R, G, and B, respectively, and plotted against the wave lengths of preilluminating spectral lights. For reasons stated in a previous paper (9), the quantities R, G, and B represent

excitations of red, green, and blue receptors, respectively. The response curves shown in the middle diagram were obtained in the manner stated above, using two flashes of white light variously spaced and a subsequent white stimulus 2 sec. in duration. When the interval was shorter than 90 msec. or longer than 170 msec., the flashes showed no color-inducing effect whatsoever, and the ζ-time curve was found to be the same as that for white light alone. However, at intermediate intervals from 90 to 170 msec. very striking color induction could be seen; as the interval was increased, the relative magnitudes of R, G, and B were systematically altered in such a manner that the induced color changed from violet to red in the same order as in a spectrum (compare the upper and the middle diagrams).

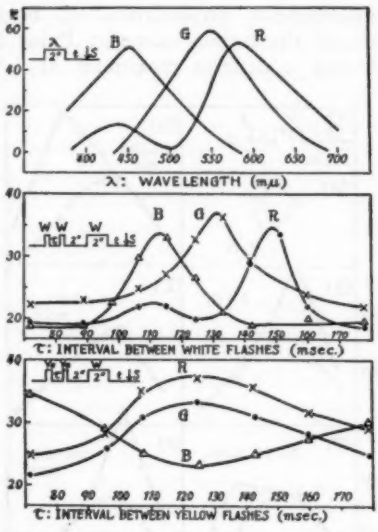

FIG. 1. Response curves for an equal-energy spectrum (upper diagram) and those for intermittent white light (middle diagram) and for intermittent yellow light (lower diagram). Experimental procedure is shown in insets, in which W, Ye, S, and t denote white light, yellow light, electrical stimulation, and the interval between W and S, respectively. Duration of each flash was 36 msec.

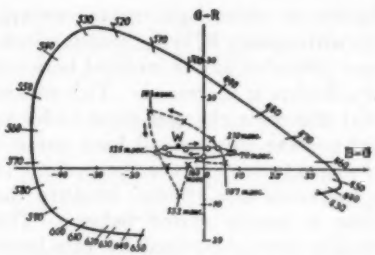

FIG. 2. Physiological color diagrams. The largest diagram represents a spectral locus obtained from the upper set of curves in Fig. 1. Broken curve is a locus constructed from the middle set of curves in Fig. 1. Elliptic curve marked by circles is a locus obtained from the lower set of curves in Fig. 1.

In the next series of experiments, two flashes of sodium yellow light were used instead of white flashes, the other experimental conditions being the same as above. The data are shown in the lower diagram of Fig. 1. The change of B is generally opposite to those of R and G in this diagram, and these changes correspond to color changes from blue to yellow and back to blue. This relation may be illustrated more clearly by the third method.

The largest diagram shown in Fig. 2 is a physiological color diagram, constructed from the data shown in the upper diagram of Fig. 1 by plotting the difference $G - R$ for each wave length as ordinates against the difference $B - G$ as abscissas. The numbers near the diagram indicate wave lengths, and the point W corresponds to white light. The full account of this diagram is given in a previous paper (8). The broken curve marked by crosses is a locus obtained in a similar manner from the data shown in the middle diagram of Fig. 1. As can be seen in this locus, the point representing the color induced by

flashes of white light moves around the white-point *W* in the counterclockwise direction as the interval between two flashes is increased. This means that the color changes from violet to red passing through all hues present in a spectrum. (Hues not present in a spectrum can appear, because the locus is nearly closed below.) The smaller area comprised by this locus shows a low degree of saturation of the induced colors as compared with spectral colors.

The curve marked by small circles represents a locus constructed from the lower set of curves in Fig. 1. It is an ellipse with its major axis parallel to the line connecting the yellow and the blue parts of the spectral locus. It is apparent from this locus, that the color induced by yellow flashes swings to and fro between blue and yellow passing through a series of various but unsaturated colors. In this manner, retinal processes underlying the so-called subjective colors can quantitatively be studied.

Conversion of retinal induction in the space between two stimuli.—In the preceding section we have dealt with the conversion at the site of photic stimulation. In the present section, however, the conversion in the space between two stimuli is the subject of investigation. It is known that around a retinal image a field of retinal induction is set up, which is in character complementary to the one found in the area directly illuminated (**8**). Motokawa (**10**) termed the induction set up within the area illuminated "direct induction," and the one found in its surroundings "indirect induction."

It has been revealed by the present investigation that when two flashes of yellow light fall on different areas of the retina within an adequate interval, there occur striking changes in character, magnitude, and spatial distribution of retinal induction.

The arrangement of stimuli used in this experiment is shown in Fig. 3*A*. Two yellow lines, *a* and *b*, 10 mm. long and 2 mm. wide, were presented in succession at right angles at a distance 40 cm. from *O*'s eye. The exposure time of each stimulus was fixed at 38 msec. and their intensity also fixed. The white test-light, a spot 2 mm. in diameter, was presented for 2 sec. at various points in the field between the yellow stimuli. The interval between the yellow stimuli and the white test-light may be arbitrary, for it has no effect upon the result, but it was fixed at about 3 sec. in our experiment. ζ-time curves were obtained as usual by measuring electrical sensitivity of the eye at different times after termination of the white test-stimulus.

In Fig. 3 ζ-time curves obtained at a definite point labeled 5 in Fig. 3*A* are illustrated. The broken curves represent control curves *or* curves for the white test-light alone. In the simultaneous presentation of both stimuli the ζ-time curve at Point 5 showed a definite maximum at 1.5

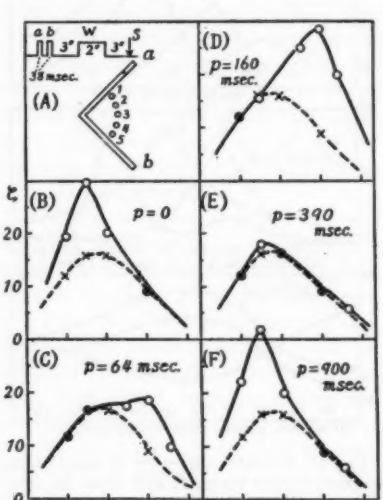

FIG. 3. Conversion of retinal induction caused by stroboscopic stimuli illustrated in (*A*). ζ-time curves for successive stimuli of varying intervals are drawn in full lines and control curves for white test-light alone in broken lines.

sec.(*B*). The maximum was, however, displaced to 3 sec. when the interval *p* was made 64 msec.(*C*). This shift of the maximum from 1.5 to 3 sec. indicates a change in character of indirect induction. As the interval was further increased, the maximum at 3 sec. increased in height (*D*), but began to decrease on further lengthening of interval. After having been reduced to the level of the control curve, the maximum was displaced to 1.5 sec. (*E*) and then increased in height to reach the same height as in the simultaneous presentation.

Similar changes were found to occur also at other points of the field between the two stimuli, although the degree of change was found different from point to point. In order to measure the direct induction at the site of stimulation, the white test-light was made to fall on the retinal area exposed to *a* or *b*, and ζ-time curves having a maximum at about 3 sec. were obtained, that is, to coincide in shape with the ζ-time curve obtained at the stage (*D*). It is now apparent that the space between *a* and *b* is filled with retinal induction of the same character as the induction at *a* or *b*. Thus, a state similar to a retinal trace behind a moving retinal image has been established by stroboscopic stimuli delivered at an interval of 160 msec. In other words, the fusion of two separate stimuli can be achieved in the retina by making the interval between them adequate.

Some kind of fusion process has been considered to be an important factor for optimal apparent movement by psychologists (**3, 4, 7**). It has been expressed in various terms, e.g., fusion, assimilation, identity, etc. Psychologists have, however, never supposed that any fusion could occur at the retinal level (**13**). Our experiments have provided evidence that what has not been expected does actually take place.

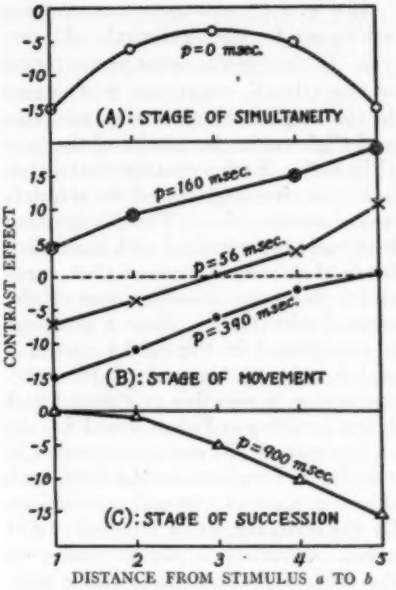

FIG. 4. Gradients of retinal induction at various stages of apparent movement. Contrast effects are differences between ζ values for successive stimuli and those for white light alone. Abscissas: distances from the first stimulus *a* to the second *b* (cf. *A* in Fig. 3).

Production of gradients of retinal induction by conversion.—The data shown in Fig. 3 were concerned with a given Point 5. Similar measurements were carried out at the other points, 1, 2, 3, and 4, to determine the distribution of conversion in the field between *a* and *b*. In view of the circumstance that ζ-time curves show a maximum either at 1.5 sec. or at 3 sec., we measured only ζ values at 1.5 and 3 sec. and calculated contrast effects or differences between the ζ values and corresponding ones for white light alone. We defined conversion as positive or negative according to whether ζ-time curves have a maximum at 3 sec. or 1.5 sec.

In Fig. 4 distributions of conversion are shown for various lengths of interval. In the simultaneous presentation of two stimuli, negativity is strongest in the neighborhood of each stimulus and slightest in the middle of the field (Fig. 4*A*). Such a symmetrical distribution is characteristic of the simultaneous presentation. The distribution becomes asymmetrical with increasing interval in such a manner that negativity decreases steadily toward the second stimulus *b*. Thus a gradient is established in the field between *a* and *b*. At an interval of 56 msec. conversion is negative at Points 1 and 2, but positive at Points 4 and 5. At an interval of 160 msec. conversion is positive everywhere in the field, and this is a state of optimal conversion. On the contrary, at an interval of 390 msec., conversion is negative all over the field, but there exists still a gradient directed from *a* to *b*. When the interval is further lengthened, the direction of gradient is changed in such a manner that negativity increases from *a* to *b*. This distribution is of the same type as the distribution of indirect induction set up by *b* in a single separate presentation.

It is possible to distinguish three stages according to whether the distribution is symmetrical (Fig. 4*A*), directed from *a* to *b* in gradient (Fig. 4*B*) or from *b* to *a* (Fig. 4*C*), and the stages so distinguished correspond well to the known three stages of the stroboscopic phenomenon, namely the stage of simultaneity, stage of apparent movement, and stage of succession. The Stage *B* can further be divided into three subdivisions, namely stage of partial conversion, stage of optimal conversion, and stage of negative conversion.

These relations are shown diagrammatically in Fig. 5, in which positive and negative conversions are denoted

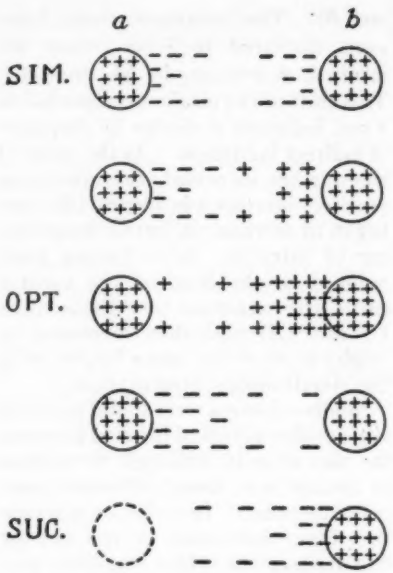

FIG. 5. Distribution of retinal induction at different stages of apparent movement: *a* and *b* represent two stimuli; plus signs denote retinal induction of the same character as the induction at the sites of direct stimulation; minus signs indicate induction of the complementary character; an empty circle indicates that induction at *a* is missing.

by positive and negative signs, the gradient being expressed by the density of these signs. At the stage of simultaneity, two stimuli, *a* and *b*, are separated from each other by complementary induction which is indicated by negative signs. By virtue of this phenomenon or simultaneous contrast, the stimuli can appear spatially separate in spite of some opposite actions such as irradiation, diffraction, and effect of stray light.

At the stage of optimal conversion, the indirect induction between *a* and *b* acquires the same character as the direct induction at *a* and *b*, so that conditions for optimal movement, namely fusion and identity, are fulfilled in this case. Our *O*s reported that

they could observe optimal movement at the stage of optimal conversion. Under our experimental conditions optimal conversion was observed for intervals of 100–160 msec. Wertheimer (17) gave 60 msec. as interval for optimal movement, but Neuhaus (14) reported that it could vary from 80 to 400 msec. according to experimental conditions. The interval for optimal conversion and that for optimal movement may therefore be regarded as of the same order.

At the stage of succession, the field between *a* and *b* resembles that set up by *b* alone; and the direct induction caused by *a* is missing. The latter phenomenon deserves special attention. It was shown by Motokawa (10) that the direct induction caused by a yellow stimulus persists for 20 sec. or longer after termination of the inducing light, but disappears at once when some other region of the retina is exposed to the second yellow stimulus. This is because the direct induction is neutralized by the spreading induction, complementary in character, set up by the second stimulus. The phenomenon of neutralization cannot be seen for short intervals and comes into action at the stage of succession. At this stage, the aftereffect of the preceding stimulus is wiped out by the action of the second stimulus, and this positive inhibitory action seems to be favorable to secure temporal disparity of the two successive stimuli.

Let us now consider the phenomenon which occurs at a stage intermediate between optimal and successive. As can be seen in Fig. 5, conversion is negative all over the field between *a* and *b*, so that they cannot become fused. It is apparent from this situation that no sensation similar to a sensation of real movement should occur at this stage. There is, however, a gradient directed from *a* to *b*. If such a gradient is essential to the perception of movement, we can expect a sensation of movement to occur at this stage, too. It must, however, be quite different in quality from the sensation of real movement, inasmuch as characteristics of real motion, fusion, and identity are lacking in this case. The phi phenomenon which has extensively been investigated (1, 2, 3, 4, 6, 13, 17) seems to correspond to what has been deduced from our findings.

At a stage intermediate between simultaneity and optimal, conversion is positive in one part of the field and negative in another, so that fusion and identity are seen only in a limited region of the field.

It is to be noted that gradients of all curves in Stage *B* of Fig. 4 are similar to one another, irrespective of the lengths of *p*. This fact was against the expectation that we should obtain the greatest gradient at the stage of optimal conversion.

If the gradient is connected with the perception of so-called pure movement, it is to be expected that a sensation of movement takes place over a very wide range of intervals. Higginson (2) obtained reports from his *O*s indicating a complete lack of dependence of the perception of movement upon length of interval.

The field between *a* and *b* can have gradients in different directions according to experimental conditions. For example, a fairly remarkable gradient is established in the radial direction when a third stimulus *c* is presented at a point on the arc drawn from the end of *a* to the end of *b*, both stimuli *b* and *c* being simultaneously presented. Wertheimer (17) reported that *c* appeared to move in the radial direction, while *a* moves

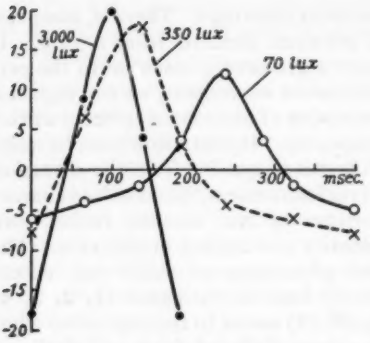

FIG. 6. Conversion of retinal induction as a function of interval between two stimuli. Ordinates: contrast effects at 3 sec. (+) and those at 1.5 sec. (−). Abscissas: interval of two stimuli. Exposure time was fixed, but intensity varied.

toward *b*. Our finding is in good agreement with this observation by Wertheimer.

Effects of various factors upon conversion of retinal induction.—In the following experiments two yellow spots, 2 mm. in diameter, were used, and conversion was measured at a point halfway between the two stimuli. Yellow light was prepared by a gelatin filter instead of by a sodium lamp. The data shown in Fig. 6 were obtained with stimuli 3 mm. apart at different intensities of illumination. It can be seen in this figure that positive conversion takes place only within a limited range of p, and that p for optimal conversion decreases with increasing intensities. This relation corresponds to one of Korte's laws concerning apparent movement (**3, 5**).

Next, the distance s between two stimuli was varied, the other conditions being held constant. The intensity of stimuli was 350 lux. As can be seen in Fig. 7, the interval p for optimal conversion increases as the distance s increases. This relation is also in good agreement with another law of Korte concerning apparent movement.

The broken curve in Fig. 7 was obtained, using two vertical bars 10 mm. long and 2 mm. wide presented 10 mm. apart from each other as stimuli. Compared with the data for the two spots 10 mm. apart, it is apparent that the interval p for optimal conversion is shorter for a larger figure than for a smaller. This finding is also in harmony with our experience on apparent movement. In this experiment the interval for optimal conversion was about 120, 210, and 490 msec. for distances 3, 6, and 10 mm., respectively. A series of similar experiments was carried out at another intensity of stimuli, namely 70 lux, and values of interval for optimal conversion—230, 450, and 770 msec.—were obtained for distances 3, 6, and 10 mm. These relations show a trend somewhat different from the functional relation between p and s determined by Koffka (**3**) for optimal movement.

Next, the distance of objective stimuli from the eye was made 30, 92, and 186 cm., and some experiments were carried out under otherwise the same experimental conditions. It was found

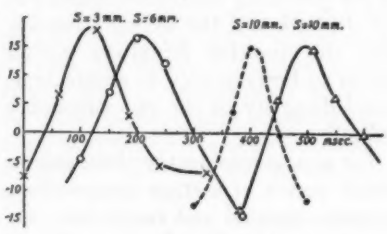

FIG. 7. Conversion of retinal induction as a function of interval between successive stimuli. Exposure time and intensity were fixed, but spatial distance s between stimuli varied. Broken curve is referred to the data obtained with stimuli of larger size 10 mm. apart (compare it with the continuous curve for s = 10 mm.).

that the interval for optimal conversion remained almost constant irrespective of distances from the eye. As the distance from the eye increases, the gradient of retinal induction was found to increase. On the contrary, the retinal stroboscopic velocity decreases, because the retinal distance between two stimuli decreases while the interval remains constant as mentioned above. From the hypothesis concerning the constancy of apparent velocity of real movement (11) it may be said that the perceived velocity of apparent movement remains, to some extent, constant, because the two kinds of changes mentioned above compensate each other.

Discussion

The problem of apparent movement is not a special problem of perception. It is concerned with various psychological phenomena and should be studied in connection with these phenomena. Nothing conclusive on the mechanism of apparent movement can be presented before our knowledge about related phenomena, such as subjective colors, fusion of flicker, etc., has been enriched by further investigations. Our experiments have revealed that these phenomena stand on a common physiological basis, namely retinal induction. Retinal induction is concerned with geometrical illusions in its static phase and with all the phenomena mentioned above in its dynamic phase.

The phenomenon of conversion represents a dynamic aspect of retinal induction. At the present stage of our knowledge it is difficult to account for this phenomenon in terms of other known physiological effects. It is, however, certain that it represents a certain physiological state in the nervous network in the retina. It is hardly conceivable that this phenomenon should be a central event, although a subjective index, electrical phosphene, is used in our experiments. (Most of the phenomena of retinal induction, including neutralization, have been shown in animal experiments with objective indices such as action-potentials of the optic nerve. It should not be difficult to demonstrate the phenomenon of conversion objectively.)

In spite of our experimental evidence that some aspects of apparent movement may be explained in purely peripheral terms, we dare not say that the perception of apparent movement is determined solely by retinal events, for there are a number of psychological facts that are difficult or almost impossible to interpret in peripheral terms. For example, binocularly induced apparent movement (15) and perception of movement in the blind spot (16) cannot be accounted for in terms of retinal events. The effects of observational conditions such as attitude, instruction, attention, etc. upon apparent movement are certainly to be ascribed to central mechanisms.

At any rate, it should be remembered that retinal events are important not only in initiating the perception, but also in providing some of its organization. In this sense the retina is a peripheral brain.

Summary

Retinal induction caused by stroboscopic stimuli was measured by the method of electrostimulation.

1. The retinal induction caused by a first stimulus is changed in character and magnitude by the action of a second stimulus successively delivered. This phenomenon is termed "conversion of retinal induction." The phenomenon of subjective color, caused by intermittent white light, may be attributed to conversion.

2. With an adequate interval between two stimuli, the induction lying in the field between the retinal areas exposed to the stimuli acquires the same quality as the induction at the site of stimulation, so that the two physically separate stimuli become fused as retinal processes. This phenomenon gives a physiological basis for the perception of fused optimal motion.

3. A gradient of retinal induction directed from the first stimulus to the second is established by conversion. The gradient is seen over a wide range

of intervals and is independent of fusion processes. If it can be shown that a gradient associated with fusion corresponds to optimal movement, then it would be conceivable that a gradient devoid of fusion corresponds to the phi phenomenon.

4. The interval for optimal conversion decreases with increasing intensities of stimuli. The interval increases as the distance between two stimuli increases. These relations correspond to Korte's laws of apparent movement.

(Received October 7, 1952)

References

1. Dimmick, F. L. An experimental study of visual movement and the phi phenomenon. *Amer. J. Psychol.*, 1920, **31**, 317–332.
2. Higginson, G. D. The visual apprehension of movement under successive retinal excitations. *Amer. J. Psychol.*, 1926, **37**, 63–115.
3. Koffka, K. *Principles of gestalt psychology.* New York: Harcourt, Brace, 1935.
4. Köhler, W. Zur Theorie der stroboskopischen Bewegung. *Psychol. Forsch.*, 1923, **3**, 397–407.
5. Korte, A. Kinematoskopische Untersuchungen. *Z. Psychol.*, 1915, **72**, 193–206.
6. McConnell, R. F. Visual movement under simultaneous excitations with initial and temporal overlap. *J. exp. Psychol.*, 1927, **10**, 227–246.
7. Marbe, K. Die stroboskopischen Erscheinungen. *Phil. Stud.*, 1898, **14**, 376–401.
8. Motokawa, K. Physiological induction in human retina as basis of color and brightness contrast. *J. Neurophysiol.*, 1949, **12**, 475–488.
9. Motokawa, K. Retinal processes and their role in color vision. *J. Neurophysiol.*, 1949, **12**, 291–303.
10. Motokawa, K. Propagation of retinal induction. *J. Neurophysiol.*, 1951, **14**, 339–351.
11. Motokawa, K. Retinal traces and visual perception of movement. *J. exp. Psychol.*, 1953, **45**, 369–377.
12. Motokawa, K., & Ebe, M. Retinal colour processes caused by intermittent white light. *Nature*, 1952, **170**, 79–80.
13. Neff, W. S. A critical investigation of the visual apprehension of movement. *Amer. J. Psychol.*, 1936, **48**, 1–42.
14. Neuhaus, W. Experimentelle Untersuchung der Scheinbewegung. *Arch. ges. Psychol.*, 1930, **75**, 315–458.
15. Smith, K. R. Visual apparent movement in the absence of neural interaction. *Amer. J. Psychol.*, 1948, **61**, 73–78.
16. Stern, A. Die Wahrnehmung von Bewegungen in der Gegend des blinden Flecks. *Psychol. Forsch.*, 1926, **7**, 1–15.
17. Wertheimer, M. Experimentelle Studien über das Sehen von Bewegung. *Z. Psychol.*, 1912, **61**, 161–265.

Journal of Experimental Psychology
Vol. 45, No. 6, 1953

THE ROLE OF STIMULUS SATIATION IN SPONTANEOUS ALTERNATION[1]

MURRAY GLANZER
Brooklyn College

It has been repeatedly demonstrated that rats, when running successive trials in a maze consisting of two equally preferred paths, show a strong tendency to change choice of paths regularly from trial to trial. This phenomenon has been labeled spontaneous alternation. Because it has theoretical implications in addition to being of interest in its own right, spontaneous alternation has been the subject of extensive research and interpretation.

In general, theoretical explanations of spontaneous alternation fall into two categories: (*a*) *Response-oriented theories* which are based on such concepts as reactive inhibition (**4**) and performance decrement (**3**). According to both these concepts, the occurrence of a response reduces temporarily the probability of its recurrence. When applied to spontaneous alternation, this explanation means that the rat turns left on the second trial because it has already made the response of turning right on the first trial and vice versa. (*b*) *Stimulus-oriented theories* which focus on the stimulus conditions which the organism faces. In all such explanations, it is at least implicit that the experience or perception of a stimulus situation alters the organism's reaction to it. In this approach the explanation of spontaneous alternation would be expressed in the following terms: the animal turns into Alley B on the second trial because it has already perceived Alley A on the first trial and vice versa.

Response-oriented concepts have formed the basis of studies on spontaneous alternation carried out by a number of investigators. By using these concepts Heathers (**3**) and Zeaman and House (**10**) have been able to predict and verify the following findings: (*a*) a decrease in spontaneous alternation with increasing time interval between successive trials (**3, 10**); (*b*) an increase in spontaneous alternation with increase in the number of forced trials to one of the two maze paths (**10**).

These findings, however, cannot be considered to constitute "crucial" tests of the validity of the reactive-inhibition explanation of spontaneous alternation, since analysis reveals that the findings are equally compatible with a stimulus-oriented theory. Moreover, the reactive-inhibition explanation cannot account for—in fact, is sometimes contradicted by—such experimental findings on spontaneous alternation as those of Dennis (**1**), Jackson (**5**), Wingfield (**9**), and others. These irreconcilable data have been summarized elsewhere (**2**).

Although it is conceivable that a response-oriented theory could be stretched and patched to contain these findings, it would seem more profitable to explore the possibilities offered by a stimulus-oriented theory. Such an approach was originally suggested by Dennis (**1**) in his explanation of spontaneous alternation as a form of "neg-

[1] This paper is based in part upon a Ph.D. dissertation submitted in February, 1952 to the department of psychology at the University of Michigan. The writer is indebted to the members of the committee and to Dr. Edward L. Walker, chairman of the committee, who gave generous aid and invaluable criticism.

ative adaptation" to specific pathways of the maze. It is also exemplified in Montgomery's (7) proposed concept of an "exploratory tendency" on the basis of which he has made a prediction identical with that of Deduction 1 given below. A comprehensive theory of this nature has been recently developed by the author (2) based on a postulate of stimulus satiation which may be condensed as follows.

Each moment an organism perceives a stimulus-object, a quantity of stimulus satiation is developed to it. The effect of this satiation is to reduce the organism's tendency to respond to that stimulus-object. The longer the organism perceives the stimulus-object, the greater the amount of satiation developed and, conversely, the amount diminishes as a function of increasing time spent away from the stimulus-object. In other words, stimulus satiation might be described as a boredom-like effect. The amount of stimulus satiation is a negatively accelerated function of time.

This postulate yields a large number of deductions. The two stated and experimentally tested below are of particular interest since the predictions made therein differ sharply from those expected on the basis of the reactive-inhibition concept.

Deduction 1.[2]—If the stimulus-objects in a two-alternative maze are exchanged between trials so that the cues that were on one side of *S* are now on the other and vice versa, *S* will *repeat* turns in successive trials in order to alternate alleys (stimulus-objects). The counter-prediction on the basis of the reactive-inhibition hypothesis for this situation would be that *S* will alternate turns (responses) since for that hypothesis the exchange of stimuli is irrelevant.

Montgomery (8) has recently verified a prediction similar to this in an experiment that varies only in minor details from Exp. I.

Deduction 2.—If *S* is delayed between choices in the simple two-alternative maze and this delay occurs within the alternative last chosen, *S* will show *more* spontaneous alternation than under a condition of no delay. If, however, the delay occurs outside the alternative last chosen, *S* will show *less* spontaneous alternation than under a condition of no delay. In other words, the amount of spontaneous alternation will be greatest with delay in the alternative itself, less without delay, and least with delay outside of the alternative last chosen.

Here again the prediction made differs from what would be expected on the basis of the reactive-inhibition concept. According to the latter, increasing the time interval between trials should decrease the amount of spontaneous alternation, regardless of the *place* where the delay occurs.

Experiment I

Essentially, the first deduction states that in spontaneous alternation *S* is alternating alleys, not responses or turns. In the conventional alternation situation, an alternation of responses is necessarily accompanied by a simultaneous alternation of alleys or vice versa. It is possible to discover whether it is alleys or responses that are being alternated only if the external cues that distinguish the two pathways are switched between the successive trials. According to the reactive-inhibition concept, *S*, after going right (let us say) on Trial 1, should then go left on Trial 2, despite the exchange of alley cues that has

[2] Deductions 1 and 2 here correspond to Deductions 2 and 10, respectively, of the author's fuller theoretical treatment (2).

been made between trials. According to the stimulus-satiation postulate, however, *S* should go right again on Trial 2, since at the choice point he perceives an already visited alley on his left and therefore goes to the "new" alley or set of cues which has been switched to his right. The repetition of turns predicted by the postulate means that spontaneous alternation consists of an alternation of alleys or stimuli rather than of responses.

Subjects.—The *S*s were 26 male albino rats, 17 of whom were approximately 240 days old, the remaining 9 being 150 days old. All *S*s had learned various mazes before serving in this experiment; none, however, had been trained to alternate.

Apparatus.—The apparatus, diagramed in Fig. 1, was a cross-shaped maze, the walls of which were constructed of wooden panels that slid into grooved posts. The posts fitted into approximately equally spaced holes on the maze table (designed after the Shepard universal maze table) which stood in the center of the experimental room. All the alleys of the maze were of the same length and width. Doors were suspended over both ends of each of the four alleys.

The walls of the two alleys leading to the end boxes, *W* and *B*, were lined with white and black cardboard, respectively, as a means of increasing their discriminability. The end boxes were further distinguished by two large rectangles of cardboard, a black one in end box *B* and a white one in end box *W*, which were fastened to the end wall and extended upward.

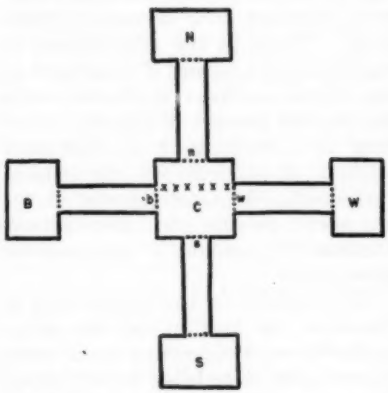

FIG. 1. Cross-shaped maze used in Exp. I. Broken lines indicate doors. The *x*'s indicate the wall that formed the choice box in Exp. II.

A recess in the south wall of the room contained a window and the home cages. The door to the room was in the north wall.

Procedure.—As can be seen in Fig. 1, when *S* is started in the South (*S*) starting box with door "*n*" down, a regular T maze is formed, with the white alley and end box to the right and the black alley and end box to the left. Similarly, when *S* is started from the North (*N*) starting box, with door "*s*" down, another T maze is formed, but this time the black alley and end box are to the right and the white alley and end box to the left.

The experiment ran for eight days, each *S* being given two successive trials per day. On half of the eight days (Days 1, 3, 6, and 8), *S*s were given both their trials from the same starting box, either the South or North one. These days are referred to as SS or NN in Table 1. On the other four days (Days 2, 4, 5, and 7), *S*s were started in the *S* (or *N*) box for Trial 1 and then placed in the opposite box for Trial 2. These days when *S*s were placed in opposite starting boxes for Trials 1 and 2 are referred to as NS or SN days. Reference to Fig. 1 will show that the NS and SN days were the days in which all of the cues (extra- and intramaze) that had been on *S*'s left in Trial 1 were switched to its right in Trial 2 and vice versa.

The procedure for handling *S*s during their trials was as follows: The *E* would place *S* in the appropriate starting box for Trial 1 and then remain hidden as much as possible until *S* had entered an end box. (If, however, *S* turned around in any part of the maze during the trial, *E* would lower the last door it had passed to prevent retracing.) If there was to be no shift in starting box for Trial 2, *E* would raise the doors that had been lowered and then remove *S* from the end box and place it in the same starting box for Trial 2. Similarly, if *S* was to be placed in the opposite starting box for Trial 2, *E* would first arrange the doors appropriately before picking *S* up. In both instances *E* took care not to turn *S* around while carrying it to the appropriate starting box for Trial 2.

Maintenance schedule.—There were no rewards in the maze. The *S*s were given their two successive trials for each of the eight days in the afternoon, approximately 1 hr. before their feeding time. At the completion of their second trial, they were returned to their home cages behind the maze table. They were fed throughout the experiment on their regular diet of three Purina pellets a day; water was kept in the home cages at all times.

Results.—Table 1 shows the frequency and percentage of alternation of turns for the 26 *Ss* on each of the experimental days. A departure of 25% in either direction from the expected chance value of 50% is required for statistical significance at the .01 level of confidence. This level is reached on six of the eight days; on Day 8 the value falls between the .05 and .01 level of confidence.

The amount of response alternation is therefore shown to be significantly higher than chance on Days 1, 3, 5, and 8, the days when the *Ss* were started from the same starting boxes,

TABLE 1

TURN ALTERNATION IN EXP. I

Day	Starting Box	Alternating Turns (RL and LR)	
		Ss	%
1	NN	22	85**
2	NS	9	35
3	SS	23	88**
4	SN	5	19**
5	SN	4	15**
6	SS	21	81**
7	NS	2	8**
8	NN	18	69*

* Significant at the .05 level (two-tailed test).
** Significant at the .01 level (two-tailed test).

and significantly *lower* than chance on Days 4, 5, and 7, when they were started from opposite starting boxes, i.e., when cues were shifted from one side of the *S* to the other between the two consecutive runs. This finding clearly verifies Deduction 1 and contradicts the reactive-inhibition prediction that the amount of alternation should be significantly higher than chance on all experimental days, regardless of the switching of cues.

The less-than-chance alternation on the SN and NS days means that *Ss* are really alternating alleys (stimulus-objects) as follows from the postulate. As can be seen in Table 1 the majority of the *Ss* alternated alleys and consequently repeated responses.

Verification of Deduction 1 therefore validates the stimulus-satiation postulate on the nature of spontaneous alternation: alleys (stimuli) rather than responses are being alternated, even when responses must be repeated in order to alternate alleys.

EXPERIMENT II

As pointed out earlier, it has been demonstrated (**3, 10**) that an increase in the time interval between successive trials decreases the amount of spontaneous alternation. This finding is reconcilable with either the reactive-inhibition or stimulus-satiation concept. There is a crucial case, however, in which the time interval is increased, and for which the stimulus-satiation and reactive-inhibition concepts lead to different predictions.

This case involves variation of a factor hitherto ignored—the *place* where the time interval between the choices of the two successive trials is spent. For the reactive-inhibition postulate, the place of delay is irrelevant, whereas for the stimulus-satiation postulate, it is of major importance. Delay in the alley chosen in the first trial prolongs *S*'s exposure to the stimuli on that side, thereby maximizing the amount of stimulus satiation and resulting in an increased amount of spontaneous alternation. Conversely, the same amount of delay spent outside the alley should decrease the amount of spontaneous alternation.

The variable in this experiment is therefore the location of the delay period between successive trials, three places in the maze being employed for this purpose: the end box (EB) of the alley chosen in Trial 1; the starting box (SB) at the beginning of Trial 2;

and the choice box (CB) before the turn for Trial 2 is made.

Subjects.—Twenty-five rats of the group run two weeks earlier in Exp. I were used. One rat of the original group of 26 had died.

Apparatus.—A T maze, one arm and end box lined with white and the other with black, was constructed by inserting a wall across the top third of the choice box in the maze used in Exp. I (see Fig. 1). This made the choice box identical with end and starting box in shape and area. Grates were placed over the end, starting, and choice boxes to prevent *S* from climbing out during the detention period.

Procedure.—The experiment ran for six days, the three experimental sessions for 12 *Ss* being run on Days 1, 3, and 5 and the three sessions for the remaining 13 *Ss* on Days 2, 4, and 6. This division was necessary because of the lengthy experimental sessions resulting from the introduction of delay periods.

Each *S* was given two successive runs during each of its three experimental sessions, a 10-min. delay being introduced at a different place at each session. For example, *S* would be delayed at EB between the two trials of the first session; at SB between the two trials of the second session, and at CB between trials of the third session. Taking three conditions, one at a time, there are six possible sequences (three factorial). Each sequence was used for four *Ss* except, of course, for one sequence which was used for five. Thus, the first *S* ran CB–SB–EB in his three sessions; the second *S* ran SB–EB–CB; the third, EB–CB–SB; etc. Thus, each *S* was delayed once in each of the three boxes.

In Cond. EB, *S* was kept for 10 min. in the end box it had entered in Trial 1, before being removed and placed in the starting box for Trial 2. In Cond. SB, *S* was removed immediately after completing Trial 1 and placed in the starting box for Trial 2, but was then confined there for 10 min. before being released and permitted to run to the choice point. In Cond. CB, *S* was removed after completing Trial 1, placed immediately in the starting box for Trial 2 and allowed to run to the choice box, where it was then confined for 10 min. before being released and permitted to complete the trial. By making the duration of the detention period the same for all three conditions, the time elapsing between the successive choices in the two trials could be considered constant.

Detention was effected in all three conditions by lowering all doors that opened on the appropriate box.

Maintenance schedule.—No rewards were used in the maze, all sessions taking place approximately one hour before *Ss'* regular feeding time. Living conditions were identical with those described in Exp. I.

Results.—Table 2 presents the total number of alternations performed by the 25 *Ss* under each of the three conditions and the corresponding percentages. The *t*'s for the differences between the correlated proportions (6) are also shown.

These results confirm the predicted differences between Cond. EB and SB and between EB and CB: delay in the end box of the alley previously visited produces a significantly greater amount of spontaneous alternation to the other alley than an equal period of detention spent outside that alley.

TABLE 2

SPONTANEOUS ALTERNATION IN THE THREE DELAY CONDITIONS OF EXP. II

Delay Condition	Alternation		*t*
	Ss	%	
SB	17	68	2.4* (SB–CB)
CB	9	36	3.9** (CB–EB)
EB	24	96	2.3** (SB–EB)

* Significant at the .05 level of confidence (two-tailed test).
** Significant at the .01 level of confidence (one-tailed test).

However, to verify Deduction 2 in its entirety, we also need to establish significant differences between the three conditions and the condition of no delay between trials or choices. Although such a condition was not included in this experiment, we may draw on Exp. I for these data, using the four days in that study that were run without switching of the starting boxes (identified as Sessions I, II, III, and IV in Table 3. To obtain comparable data for a period subsequent to Exp. II, the 25 *Ss* were run for two additional successive trials with no delay between them, one week after the experiment was completed (Session V in Table 3).

TABLE 3

t's FOR THE DIFFERENCES BETWEEN THE DELAY CONDITIONS AND EACH OF THE NO-DELAY SESSIONS†

Delay Condition	No-Delay Sessions				
	I	II	III	IV	V
SB	1.2	1.7*	1.2	0.3	0.3
CB	3.5***	3.4***	3.0***	2.3***	2.7***
EB				2.2**	2.5**

* Significant at the .10 level.
** Significant at the .05 level.
*** Significant at the .01 level.
† Three *t*'s (EB–I, II, III) have been omitted since they do not satisfy the conditions for applying the formula. All the differences including the omitted ones are in the predicted direction. All *t*'s are based on a two-tailed test of significance.

Table 3 presents the *t*'s for the differences between each of the three conditions and the "control" no-delay trials run both prior to and after Exp. II. All the differences are in the predicted directions. Of the 12 differences, 5 are beyond the .01 level of confidence and 2 are between the .05 and .01 levels of confidence.[3] As predicted in Deduction 2, the greatest amount of spontaneous alternation occurs when the detention is at the alternative previously entered, less with no delay between trials, and least with detention at a place in the maze outside of the alley last chosen.

The difference between the amounts of spontaneous alternation for Cond. CB and SB (Table 2) is of interest. This difference is significant between the .05 and .01 level. (A two-tailed test of significance, and therefore a *t* of 2.58, is required since the direction of the difference was not hypothesized.) Although the difference was not predicted, it may be explained on the basis of the stimulus-satiation postulate. The explanation stems from an examination of the meaning of the term "alternative." Ordinarily, an alternative is thought of as starting at the entrance to the maze arm. Strictly speaking, it cannot be maintained that such a demarcation exists for *S*, for whom the right half of the choice-point box may be continuous with the alternative to the right and the left half of the choice-point box continuous with the left alternative. Moreover, *S* can view from parts of the choice-point box many of extramaze stimuli that surround both alternatives. While in the choice-point box, therefore, *S* can become satiated to many of the stimuli that compose each alternative. In this connection, it was observed that *S* during the detention period would wander around the choice-point box rather than maintain a constant orientation toward one or the other alley. These increments of stimulus satiation that would accrue to *both* alternatives could be sufficient to cancel out the difference in the amount of stimulus satiation that would otherwise remain at the end of the detention period. This follows from the nature of the postulated negatively accelerated relationship between time and stimulus satiation (2). This in turn would reduce the amount of spontaneous alternation.

Why then does *S* show less spontaneous alternation than expected by chance in Cond. CB (.36 as compared with the .50 expected on the basis of chance)? If, as argued above, the amounts of stimulus satiation for the two alternatives are equalized during detention at the choice-point box, we would then expect the only important factor determining *S*'s choice in the second trial to be the specific alley or turn preferences he may have. These same preferences probably determined the first choice. In that case, repetition of the preferred response would be expected, resulting in the obtained less-than-chance frequency of alternation.

The data were also analyzed to determine the effect of the following factors on alternation: the number of the session, the sequence of conditions, and "emotion" (as measured by defecation). None of these factors appeared to be related to spontaneous alternation.

[3] The four differences that were not significant occur in the SB versus no-delay conditions. This difference has, however, been adequately supported by the findings of Heathers (3), mentioned above.

SUMMARY AND CONCLUSIONS

Two experimental tests were made to determine the validity of a stimulus- versus a response-oriented explanation of spontaneous alternation. The following deductions were derived from the postulate of stimulus satiation which assumes that exposure to a stimulus reduces the organism's tendency to respond to that stimulus.

1. Exchanging the stimulus-objects of a two-alternative maze between trials will result in a repetition rather than an alternation of turns.

2. The effect on spontaneous alternation of increasing the time interval between trials depends on the place of delay.

Deduction 1 was tested by the use of a cross-shaped maze with two starting boxes. On half of the eight experimental days, 26 rats started from one starting box for the first trial and from the opposite box for the second immediately consecutive trial. On these days, *Ss* showed the predicted alternation of alleys (stimuli) even though this required repetition of turns.

To test the second deduction, 25 rats were run in a simple **T** maze, two trials a day for three sessions. A delay of 10 min. in the alley chosen in the first trial produced the greatest amount of spontaneous alternation; less alternation occurred with no delay between trials and least when the delay took place outside the alley last chosen.

The confirmation of both predictions indicates that the concept of reactive inhibition cannot explain the phenomenon of spontaneous alternation. It is equally evident that the explanation resides in the effects which exposure to stimuli has on the organism.

(Received October 6, 1952)

References

1. Dennis, W. Spontaneous alternation in rats as an indicator of the persistence of stimulus effects. *J. comp. Psychol.*, 1939, **28**, 305–312.
2. Glanzer, M. Stimulus satiation: an explanation of spontaneous alternation and related phenomena. *Psychol. Rev.*, in press.
3. Heathers, G. L. The avoidance of repetition of a maze reaction in the rat as a function of the time interval between trials. *J. Psychol.*, 1940, **10**, 359–380.
4. Hull, C. L. *Principles of behavior.* New York: D. Appleton-Century, 1943.
5. Jackson, M. M. Reactive tendencies of the white rat in running and jumping situations. *J. comp. Psychol.*, 1941, **31**, 255–262.
6. McNemar, Q. *Psychological statistics.* New York: Wiley, 1949.
7. Montgomery, K. C. Spontaneous alternation as a function of time between trials and amount of work. *J. exp. Psychol.*, 1951, **42**, 82–93.
8. Montgomery, K. C. A test of two explanations of spontaneous alternation. *J. comp. physiol. Psychol.*, 1952, **45**, 287–294.
9. Wingfield, R. C. Some factors influencing spontaneous alternation in human subjects. *J. comp. Psychol.*, 1942, **35**, 237–244.
10. Zeaman, D., & House, B. J. The growth and decay of reactive inhibition as measured by alternation behavior. *J. exp. Psychol.*, 1951, **41**, 177–186.

Journal of Experimental Psychology
Vol. 45, No. 6, 1953

ACT REGRESSION AS A SPECIAL CASE OF RETROACTIVE INHIBITION AND FUNCTIONALLY RELATED TO STIMULUS GENERALIZATION[1]

ELI SALTZ

State University of Iowa[2]

The present experiment is concerned with the strength of a response after a second, competing response has been learned. In human learning this competing response situation traditionally has been associated with retroactive inhibition. In animal studies this situation has been used in studies involving what is called "instrumental act regression." That the two areas of study (retroactive inhibition and act regression) are extremely similar can be shown by examining the technique typically used in act-regression studies. In such studies, one response (e.g., turning left in a T maze) is established to a particular stimulus and then is extinguished while a competing response (e.g., turning right in a T maze) is developed to the same stimulus. Upon presentation of a new stimulus such as a momentary electric shock at the choice point during the acquisition of the second response, the animals often tend to exhibit the first (extinguished) response more frequently than the more recently learned second response. Thus, the act-regression technique can be described operationally as a modified retroactive transfer paradigm (A–B, A–K, A′–B′) in which the modification in the relearning stage involves a change in the stimulus conditions.

The present writer, in a previous paper (6), has proposed a theoretical model to predict the probability of recovery for responses lost in competing response situations. The model is a modification of Spence's transposition theory (9). Briefly, it proposes that each time a particular response (R_1) to a given stimulus (S_0) is rewarded, a hypothetical excitatory tendency of S_0 to elicit R_1 is increased. However, each time R_1 is elicited by S_0 either overtly or covertly, and no reward occurs, a hypothetical inhibitory tendency of S_0 *not* to elicit R_1 is increased. The excitatory and inhibitory tendencies between S_0 and R_2 are assumed to summate algebraically; the algebraic difference between the excitatory and inhibitory strengths of an S_0–R_1 connection will henceforth for convenience be referred to as the E–I strength of S_0 to elicit R_1. When two incompatible responses, R_1 and R_2, compete for elicitation, the difference in E–I strengths of the two tendencies is assumed to determine the response made. It is also assumed that stimuli other than S_0 acquire a tendency to elicit and inhibit R_1 as a result of generalization of excitatory and inhibitory tendencies. Inhibition, however, is assumed to generalize less than excitation.

In terms of the model sketched above, the typical act-regression study consists of the development of an excitatory tendency of S_0 to elicit R_1,

[1] This paper is part of a dissertation submitted to the Department of Psychology, the State University of Iowa, in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The writer wishes to express his appreciation to Prof. Harold P. Bechtoldt, under whose direction it was conducted. The writer also wishes to thank Prof. G. Robert Grice, who read and criticized the manuscript for this paper.

[2] Now at the Technical Training Research Laboratory, Human Resources Research Center, Chanute Air Force Base, Illinois.

followed by the development of inhibition to R_1 and excitation to R_2 as R_1 is no longer reinforced and R_2 is regularly rewarded. The introduction of an electric shock at the choice point alters the stimulus complex from S_0 to some generalized stimulus S_j. Since inhibitory tendencies diminish more rapidly as a function of stimulus generalization than do excitatory tendencies, the E–I strength of R_1 increases. Whether or not R_1 will occur more frequently than R_2 at S_j depends on the relative number of reinforcements originally received by each. It also depends on the degree of stimulus change. As can be seen in Fig. 1, the E–I strength of R_1 first increases, then decreases as a function of stimulus alteration.

The theoretical model is thus far capable of predicting the results obtained in act-regression studies. Hamilton and Kreshevsky (2), Kleemeier (3), Sanders (7), Martin (4) and others have shown that electric shock at the choice point, after the consecutive learning of R_1 and R_2, results in an increased tendency for R_1 to reoccur. O'Kelly (5) has shown that the electric shock is not crucial; he obtained regression by altering the animals' drive state by satiating them. Altered drive level is obviously a stimulus alteration within the meaning of that term in the theoretical model. Kleemeier (3) and Martin (4) have shown that the degree of regression is a function of the relative number of reinforcements to R_1 and R_2.

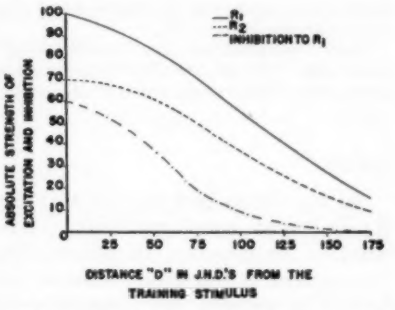

FIG. 1. Hypothetical generalization gradients of excitation and inhibition. For illustrative purposes, the equation for generalized excitation was taken as $E_j = E10^{-.000035d^2}$ and the equation for generalized inhibition was taken as $I_j = E10^{-.00005d^2}$. The E_j and I_j represent excitatory and inhibitory strengths, respectively, at a generalized stimulus j; d is the distance in j.n.d.'s between j and the training stimulus. These parameters are arbitrarily selected and are not intended even as approximations of the correct parameters. However, any parameters should show the same tendencies for interaction characteristics between responses as the above parameters, as long as the inhibition gradient falls more rapidly than the excitation gradient.

The present experiment is an attempt to apply the experimental model to paired-associates verbal learning. Utilizing the modified retroactive transfer paradigm discussed earlier, the model predicts the greater strength of R_1 (the first learned list) to a generalized stimulus than to the original stimulus.

EXPERIMENT I

Method

Experimental design.—A two-variable factorial design with four variations of each variable was used in this experiment. The dependent variable was the frequency of occurrence during a test trial of a response, R_1, which had previously been learned to a stimulus, S_0, and had then been replaced by a second response, R_2, to the same stimulus. The two independent variables were: (*a*) the difference along a generalization dimension between the training stimulus, S_0, and the stimulus to which S responded during the test trial; and (*b*) the number of reinforcements to S_0–R_2 during the original learning, reinforcements being defined in terms of the number of correct anticipations to R_2.

Material and apparatus.—The stimulus-difference variable was manipulated by the use of a modification of Yum's rules for stimulus alteration (10). Nonsense syllables were used as the stimulus members of the paired-associates learning material. Each stimulus consisted of two three-letter syllables connected by a hyphen. The first and third letters of each syllable were consonants; the second letter of each syllable

was a vowel. This material lent itself to the construction of a standard list (S_0) of ten stimuli and three other lists (S_1, S_2, S_3) which varied in the number of letters substituted for those of the S_0 list. It we let X's stand for the original letters in S_0 and Y's for alteration of the original terms, the rules for altering S_0 were as follows:

(S_0) XXX—XXX
(S_1) XXX—YYX
(S_2) XYX—YYX
(S_3) XYY—YYX

A particular consonant was used only once in a given position in any one list. Duplication of consonants or vowels within a given two-syllable nonsense term was also avoided.

The responses consisted of two lists, R_1 and R_2, each containing ten adjectives. The R_1 and R_2 responses paired with a given nonsense syllable were synonyms rated by Haagen (1) as being fairly dissimilar. Synonyms were used for reasons not relevant to the present paper.

The apparatus used was a modification of a unit designed by Shephard and Lewis (8). The device differed from the more usual memory drum chiefly in that it permitted *E* to remove from the list, either temporarily or permanently, any S–R pair, since each pair was on a separate card. This flexibility permitted the establishment of a specific criterion for each S–R pair in a list.

The *S* was allowed to see the stimulus only for 2 sec., then the shutter raised and both stimulus and response were visible together for 5 sec.

Subjects and procedure.—Ninety-six State University of Iowa students served as *Ss*. On the first day of the experiment, each *S* learned a practice list of six paired associates having geometric figures as stimuli and three-digit numbers as responses. A criterion of two correct anticipations of each response was used. The procedure for establishing the criterion will be discussed in some detail since it is similar to the procedure used throughout the rest of the experiment. Since a criterion was established separately for each stimulus pair, each pair was removed from the list as soon as its response member had been correctly anticipated. This left a list of S–R pairs which had not been correctly anticipated. These were randomized and replaced in the apparatus to be "run" again. This procedure was followed until all six responses had been correctly anticipated. Then the entire list of six pairs was randomized and replaced in the apparatus to permit the second correct anticipation of each response. The length of time between "runs" depended on the number of cards to be replaced in the apparatus. The time to randomize and replace a list in the apparatus averaged about 2 sec. for each card.

Immediately upon satisfying the criterion on the practice list, each *S* learned the R_1 response list to the standard stimulus list (S_0–R_1). Learning was to a criterion of nine correct anticipations of each adjective. Twenty-four hours later, each *S* learned the R_2 response list to the standard stimulus list (S_0–R_2). Four groups of 24 randomly selected *Ss* learned the R_2 response list to 3, 6, 9, and 12 correct anticipations, respectively.

Upon completing the S_0–R_2 task, each *S* spent 10 min. on a card-sorting task. Immediately upon completion of the card sorting, *S* returned to the verbal learning apparatus. He was then presented with one of the four stimulus lists (S_0, S_1, S_2, or S_3) to be used in the controlled-association phase of the experiment. Six *Ss* from each of the four reinforcement conditions were presented each degree of stimulus remoteness, i.e., there was a total of 24 *Ss* at each degree of stimulus remoteness.

For the controlled-association phase, each *S* was instructed to give whichever response came to his mind first of the two responses he had learned to the particular stimulus to be presented or to a stimulus similar to the one to be presented. Since no response words appeared on the cards during the controlled-association trials each *S* received, *S* was allowed 7 sec. for his response (i.e., 2 sec. with the shutter closed plus 5 sec. with the shutter open).

Each *S* was given two such controlled-association trials. The number of R_1 responses given during these trials constituted the index of act regression.

Results

As the means and variances of the R_1 responses were positively correlated, a square-root transformation was applied to the data. This transformation secured the independence of means and variances required for the analysis of variance reported in Table 1.

With increased numbers of reinforcements to R_2, the frequency of R_1 evocation during the controlled association decreased. This tendency, as can be seen in Table 1, is significant at beyond the 5% level of confidence and corresponds to expectations from the theoretical model presented above.

However, the crucial prediction from the model was not sustained by the

TABLE 1

ANALYSIS OF VARIANCE RELATING THE TRANSFORMED NUMBER OF REGRESSION RESPONSES (R_3) TO STIMULUS GENERALIZATION AND NUMBER OF CORRECT ANTICIPATIONS OF R_2

Source	*df*	Mean Square	*F*
Generalization	3	13.667	10.330**
Number of correct anticipations to R_2	3	4.793	3.623*
Interaction	9	1.645	1.357
Within cells	80	1.212	
Pooled error term	89	1.323	

* Significant at the 5% level.
** Significant at the 1% level.

data from this experiment. These data indicate that increased stimulus alteration does not result in greater numbers of R_1 responses as predicted. Instead, as illustrated in Fig. 2, the number of R_1 responses given in the controlled-association trials decreases in a relatively monotonic fashion with successive changes in the degree of alteration of the stimulus syllables. This decrement, as can be seen from Table 1, is significant beyond the 1% level of confidence.

Discussion

It might be significant to note that in the present experiment the *Ss*' set during the controlled-association trials was different from their set during the learning trials. Not only were the instructions different (i.e., in one case *Ss* were instructed to learn, in the other case to give controlled associations) but the time limitations on speed of response were different. During learning the *Ss* had only 2 sec. in which to respond; during the controlled-association trials they were permitted 7 sec. for each response.

If certain testable assumptions are made concerning the effects of the above-described set alteration, the lack of act regression in the present experiment is explainable in terms of the theoretical model.

Regression was predicted in the present experiment because inhibition to R_1 was postulated as diminishing more rapidly than excitation to R_1 as a function of stimulus alteration. Consequently, stimulus alteration produces a progressive increment to the E–I strength of R_1. However, according to the theoretical model as it is illustrated in Fig. 1, the asymptote of generalized inhibition is reached before generalized excitation reaches its asymptote. After reaching its asymptote, inhibition is practically a constant in the E–I formula; therefore, reductions in absolute excitation with stimulus alteration produces a decreasing E–I strength for R_1. In Fig. 1 the E–I strength of R_1 changes from one of progressive increases to one of progressive decreases as a function of stimulus alteration at about 125 j.n.d.'s.

Suppose that, in the present experiment, the change from a learning to a controlled-association set resulted in an internal stimulus change for *S* which was so great that the training stimulus situation was altered to the point at which

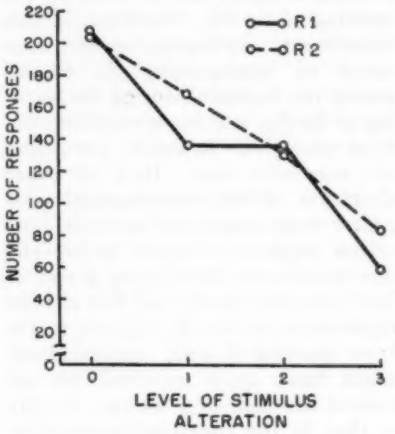

FIG. 2. Total number of R_1 and R_2 responses given during the two controlled-association test trials at each level of stimulus alteration

the inhibition reached an asymptote. Further stimulus alteration, accomplished by manipulation of the nonsense syllables, would result in a progressive weakening of the E–I strength of R_1; therefore, the tendency for R_1 to be elicited would be lessened as a function of increased syllable alteration. Since the strength of R_2 drops in a monotonic fashion as a function of stimulus alteration, the consideration of R_2 as competing with the E–I strength of R_1 does not modify the above relationship between stimulus alteration and the tendency for R_1 to be elicited.

The above explanation was tested in Exp. II, reported below, in which an attempt was made to minimize set alteration between learning and test trials.

Experiment II

This experiment was designed to minimize the effects of set alteration between the trials in which R_1 and R_2 were learned and those in which regression was being tested as a function of nonsense-syllable alteration. Whereas in Exp. I there was a change from a learning set in the first part to a controlled-association set in the regression test, in the present experiment an attempt was made to retain a learning set throughout. As in Exp. I, the learning of S_0–R_1 was followed by the learning of S_0–R_2. However, in this experiment, the regression test consisted of interspersing S_1 stimuli among the S_0 stimuli during the learning of S_0–R_2, and no special instructions were given *S*s before presenting the regression test. Had no other alteration of the experimental procedure been made, two obvious difficulties might have acted to prevent this experiment from being a test of the theoretical model: (*a*) The sudden appearance of the S_1 stimuli might have startled *S* and, consequently, might have again modified his set toward the task in a manner similar to that in the controlled-association experiment. To meet this difficulty, unfamiliar nonsense-syllable stimuli were introduced periodically into the S_0–R_1 list in order to habituate *S*s to the sudden appearance of new stimuli; (*b*) being under the set to give R_2 responses during the test for regression (since the test intrudes into the learning of S_0–R_2), *S*s might be expected to attempt suppression of R_1 responses whose excitatory strengths might otherwise have caused them to be verbalized. To meet this difficulty, two precautions were taken. First, the *S*s were encouraged to respond as quickly (i.e., unthinkingly) as possible. Second, an attempt was made by *E* to create a maximum of uncertainty as to what the correct response was. This was done by briefly presenting S_0–R_2 before teaching S_0–R_1 on the first day. On the second day, S_0–R_1 was presented briefly before S_0–R_2 was taught.

Method

Subjects and procedure.—Eleven students from the introductory psychology class at the State University of Iowa were presented the S_0–R_2 list described in Exp. I and learned each pair to a criterion of one correct response. Next, the *S*s were instructed to respond to each stimulus even if they were not certain, before the shutter raised, what the response under the shutter was. Then the S_0–R_1 list was presented to the *S*s and was learned to a criterion of nine correct anticipations of every response.

After the second correct anticipation of the entire S_0–R_1 list the *S*s were instructed that occasionally the stimuli would be shown them but no responses would be present under the shutter. The *S*s were instructed to attempt to give the correct responses for each of the stimuli just as if the responses were under the shutter. They were also instructed that unfamiliar stimuli might be occasionally presented. These stimuli, the *S*s were told, would be similar to stimuli to which they had previously learned responses. Therefore, they were told, the responses learned to the familiar stimuli, to which the new stimuli would be similar, should be given upon the appearance of the new stimuli.

After the second, third, and fourth correct anticipation of the entire list *S*s were presented with the S_0 stimuli, but no responses were indicated under the shutter. Two unfamiliar stimuli were inserted into the list of S_0 stimuli during each habituation trial. The two unfamiliar stimuli had the same form as the other stimuli (i.e., two three-letter syllables joined by a hyphen). However, the stimuli did not resemble any specific S_0 or S_1 stimulus.

After the sixth, seventh, and eighth correct anticipation of all the S_0–R_1 responses, the *S*s were told they were being timed and should respond as quickly as possible.

After 24 hr. each *S* was again presented with S_0–R_1 until each response was correctly anticipated once.

Without warning, eight S_0–R_2 along with two of the previous S_0–R_1 pairs were presented. This list was learned to a criterion of three correct anticipations of each S–R pair. After the second and third correct anticipations, the *S*s were told

to respond as quickly as possible since they were being timed.

After the third correct anticipation, again with no warning, they were presented with the crucial test list of stimuli. No responses were under the shutter in this trial. This trial resembled closely, therefore, the habituation trials of the first day.

For the test trial, the *Ss* were randomly placed in two groups, Group I having six *Ss* and Group II having five *Ss*. Each *S* in each group was presented with four S_0 stimuli that had previously been paired successively with an R_1 and an R_2 response; each *S* also was presented with four S_1 stimuli whose S_0 version had previously been paired successively with an R_1 and then an R_2 response. In addition, each *S* was presented with the two S_0 stimuli that had not been paired with an R_2 response during the second day. The S_0 and S_1 stimuli that had been paired with R_1 and R_2 were counterbalanced between the two groups. A syllable whose S_0 version was presented to Group I was presented in its S_1 version to Group II, and vice versa.

Results

In counting the number of regression (R_1) responses, the responses to the two S_0 stimuli that had not been paired with R_2 responses were ignored; since R_1 was the ongoing response to these stimuli during the regression test, an R_1 response did not represent regression for these stimuli.

The number of regression responses given to the four relevant S_0 and the four S_1 stimuli was tallied for each *S*. As is evident from Table 2, the mean number of regression responses to S_0 was similar in Groups I and II as were the mean number of regression responses to S_1. Therefore, the two groups were combined. It should be noted that in both groups more regression occurred to S_1, the generalized stimuli.

TABLE 2

NUMBER OF REGRESSION RESPONSES TO THE TRAINING (S_0) AND THE ALTERED (S_1) STIMULI WHEN SET ALTERATION HAS BEEN MINIMIZED

Group	Mean Number of R_1 Responses to	
	S_0	S_1
I	.3	1.8
II	.4	1.2

Nine of the 11 *Ss* gave more regression responses to S_1 than to S_0. The remaining two *Ss* gave an equal number of each. No *S* gave more regression responses to S_0 than to S_1. Dividing the tied scores between the two stimulus classes for purposes of a statistical test gives ten *Ss* who showed more regression to S_1 than to S_0 and one *S* who showed more regression to S_0 than S_1. An expansion of the binomial theorem indicates that we can reject the hypothesis of no difference between the amount of regression to S_0 and S_1 at the .6% level of confidence.

The number of regression responses given to the four S_0 stimuli was subtracted from the number given to the four S_1 stimuli for each *S*. The distribution of difference scores was relatively normal. The mean difference score was 1.53. With a standard error of the difference of .23, t was 5.13. This is significant beyond the .1% level for 10 *df*.

These results tend to indicate that, when set alteration is minimized, regression is a function of stimulus alteration.

SUMMARY

The present experiments attempted to show the structural similarity between act regression and certain aspects of retroactive inhibition; they then attempted to test the prediction of act regression in human verbal learning on the basis of a theoretical model described more fully elsewhere. The model states that the learning of S_0–R_2 after S_0–R_1 is established results in inhibition accruing to S_0–R_1. Inhi-

bition is assumed to generalize less than excitation; therefore, altering S_0 should, within limits, tend to produce recurrence of the extinguished R_1.

The model was tested with paired associates using the anticipation method of presentation during the learning of S_0–R_1 and S_0–R_2. A controlled-association method was used to test the strength of R_1 to various levels of stimulus alteration. The prediction of increased R_1 strength to altered stimuli was not sustained.

Since learning had been by the anticipation method and the test for regression had been by a controlled-association method, the possibility existed that an altered "set" had produced an amount of generalization maximal for regression; further S_0 alteration would then be ineffective. Consequently, a second experiment was performed in which an attempt was made to minimize "set" alteration. In this experiment, alteration of S_0 resulted in an increased tendency for R_1 to reappear. This act-regression tendency was significant at beyond the .1% level of confidence.

(Received September 29, 1952)

References

1. Haagen, C. H. Synonymity, vividness, familiarity, and association value ratings of 400 pairs of common adjectives. *J. Psychol.*, 1949, **27**, 453–463.
2. Hamilton, J. A., & Krechevsky, I. Studies in the effect of shock upon behavior plasticity in the rat. *J. comp. Psychol.*, 1933, **16**, 237–253.
3. Kleemeier, R. W. Fixation and regression in the rat. *Psychol. Monogr.*, 1942, **54**, No. 4 (Whole No. 246).
4. Martin, R. F. "Native" traits and regression in the rat. *J. comp. Psychol.*, 1940, **30**, 1–16.
5. O'Kelly, L. I. An experimental study of regression. II. Some motivational determinants of regression and perseveration. *J. comp. Psychol.*, 1940, **30**, 55–95.
6. Saltz, E. A single theory for reminiscence, act regression, and other phenomena. *Psychol. Rev.*, 1953, **60**, 159–171.
7. Sanders, M. J. An experimental demonstration of regression in the rat. *J. exp. Psychol.*, 1937, **21**, 493–510.
8. Shephard, A. H., & Lewis, D. A new device for presenting paired associates in verbal learning. *Amer. J. Psychol.*, 1950, **63**, 600–606.
9. Spence, K. W. The differential response in animals to stimuli varying within a single dimension. *Psychol. Rev.*, 1937, **44**, 430–444.
10. Yum, K. S. An experimental test of the law of assimilation. *J. exp. Psychol.*, 1931, **14**, 68–82.

Journal of Experimental Psychology
Vol. 45, No. 6, 1953

TRANSFER OF PREDIFFERENTIATION TRAINING IN SIMPLE AND MULTIPLE SHAPE DISCRIMINATION[1]

MALCOLM D. ARNOULT

Perceptual and Motor Skills Research Laboratory, Human Resources Research Center

Improvement of performance on a complex perceptual task is presumably contingent upon increasing the effectiveness of the information presented to the observer. Put another way, improvement may be demonstrated by a decrease in the amount of information required to elicit the correct response, or judgment. The more cues capable of eliciting the correct response there are, the more the stimulus may be impoverished without a corresponding significant decrease in the probability of occurrence of that response. The task of training in perception, then, is to increase the distinctiveness of the relevant stimulus cues relative to the nonrelevant ones, thus, in effect, increasing the number of cues capable of eliciting the correct response.

This study investigated the possibility of using the technique of stimulus predifferentiation as a means of improving the discrimination of nonmeaningful two-dimensional shapes. Gibson's original predifferentiation hypothesis, developed in connection with verbal learning problems, was stated as follows: "If differentiation has been set up within a list [of paired-associate items], less generalization will occur in learning a new list which includes the same stimulus items paired with different responses; and the trials required to learn the new list will tend to be reduced by a reduction of the internal generalization" (**5**, p. 222). This predicted positive transfer would be due primarily to a reduction in the number of intralist "confusions" and would be expected to evidence itself in a situation in which interlist response generalization was at a minimum.

This reduction in the number of intralist confusions would imply that *S*'s perception has in some way changed so that the stimulus items are now more "distinctive." Such a change should be detectable in terms of the accuracy and latency of detection or discrimination of those same stimulus items.

In 1950 Gagné and Baker reported positive transfer in a study of the effect of verbal pretraining on discrimination-reaction performance (**4**). Rossman and Goss (**14**) and Hovland and Kurtz (**8**) have also published data which are at least partly in accord with the predifferentiation hypothesis. In none of these studies, however, can the positive transfer be attributed unequivocally to the pretraining as such, because in all of them there was the possibility of transfer in terms of elements not specific to the stimulus items.

One possible kind of explanation for positive transfer in these studies would be based on a transfer of elements which are not specific to the stimulus material, but which are specific to the experimental tasks or procedures. Included in this class would be explanations in terms of "warm-up" (**9, 16**) or "learning-how-to-learn" (**6**). It seems clear that Gibson did not have

[1] The data reported in this study were collected as part of the United States Air Force Human Resources Research and Development Program. The opinions or conclusions contained in this report are those of the author. They are not to be construed as reflecting the views or indorsement of the Department of the Air Force.

these factors in mind when she formulated her hypothesis. It appears more likely that she envisioned the transfer in terms of factors specific to the material rather than specific to the task. Transfer in terms of factors specific to the stimuli might result, for example, from an increase in the meaningfulness of the stimuli. If meaningfulness is measured in terms of the number of independent associations linked with a stimulus item (**11**), it would seem reasonable that adding a new association to a particular stimulus (by predifferentiation training) should make subsequent learning of that stimulus item easier. Another explanation could be that during predifferentiation training there is consistent reinforcement of attention to the cues unique to each stimulus and inconsistent reinforcement of attention to the cues common to all the stimuli in the list (**3**). Thus, an increase in "distinctiveness" would occur as a function of learning to attend selectively to the relevant cues and to ignore the nonrelevant ones.

In none of the three studies cited earlier (**4, 8, 14**) was there adequate control of the factors of "warm-up" and "learning-how-to-learn." Consequently, the positive transfer which was obtained could possibly be due to elements specific to the task rather than specific to the stimulus items. The present study was so designed that any positive transfer obtained could only be attributed to factors specific to the stimulus material itself.

Experiment I

In this experiment *S*s were given predifferentiation training consisting of ten trials of paired-associate learning on each of five nonsense shapes, then tested on their ability to discriminate these shapes as different from a standard shape they had not previously seen. One experimental group (Group C) learned to pair letters of the alphabet with the nonsense shapes which later were used in testing discrimination. A second group (Group A) was given identical training, except that the nonsense shapes were different from the ones to be discriminated later. The control group (Group NP) was tested on discrimination without any predifferentiation training.

Method

Apparatus.—The paired-associate material was exposed by means of a large board containing two windows facing *S*. The stimulus and response cards were placed in slots behind the windows and exposed by means of manually operated sliding doors. The nonsense shape appeared in the left-hand window, and its associated letter appeared in the right-hand window. The *E* controlled the timing of the exposures by means of a continuously running clock.

In the discrimination task the stimuli were projected onto a portable screen by means of 2 × 2-in. slides. The projector was equipped with an Alphax shutter and mechanical and electrical controls so arranged that opening the shutter started a clock. The shutter was closed

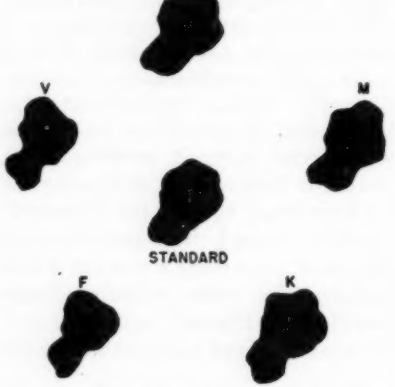

Fig. 1. The nonsense figures used in the pretraining of Group C and in testing simple discrimination for all groups. The "standard" in the center was not used during the pretraining. Beside each figure is the letter which *S* was to learn to associate with it.

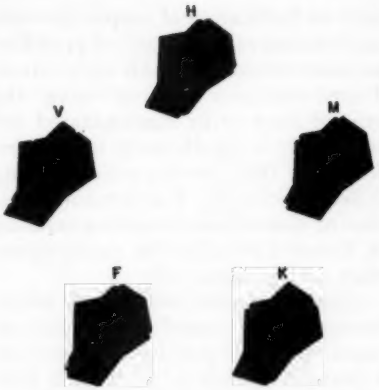

FIG. 2. The nonsense shapes used in pretraining Group A. Beside each shape is the letter which *S* was to learn to associate with it.

and the clock stopped when *S* pressed either of two keys marked "S" (Same) and "D" (Different). In this arrangement the exposure time was equal to the reaction time.

Stimuli.—The nonsense shapes used in the predifferentiation training of Group C and in the discrimination task for all groups are shown in Fig. 1. The shape in the center is the standard which was used in the discrimination task. Group A was given predifferentiation training on the nonsense shapes shown in Fig. 2. A preliminary experiment with 20 *S*s showed the shapes in Fig. 2 to be slightly, but not significantly, more difficult to learn than the shapes in Fig. 1. This difference proved to be consistent throughout the two main experiments, but the results were such that the final conclusions were not affected by it.

Subjects.—The *S*s were 250 basic airmen at Lackland Air Force Base. They were assigned at random to the various groups. There were 100 in Group C, 100 in Group A, and 50 in Group NP.

Predifferentiation training.—Each *S* in Groups C and A was allowed to study the pairs to be learned for 2 min. before the paired-associate learning proper began. Five cards bearing the stimulus shapes were laid out on a table along with five cards bearing the letters which were paired with them (F, K, H, M, and V). The same response letters were used for Groups A and C, although the stimulus shapes differed. After 2 min. of study *S* was seated in front of the exposure device and instructed to call out the proper letter as each shape appeared in the left-hand window. The shapes were exposed for 2 sec., and shape and letter were exposed together for 5 sec. Each *S* received a total of ten trials of paired-associate training. The entire series of 50 observations was arranged in a predetermined unbiased order which was the same for every *S*.

Discrimination task.—The *S* was seated in front of the screen and instructed to report as quickly as possible whether the two shapes were "Same" or "Different" when they appeared. He indicated his judgment by pressing one of two keys marked "S" and "D." After saying "Ready," *E* opened the shutter, exposing the pair of shapes and starting the clock. When *S* indicated his response, the shutter closed and the clock stopped. The next stimulus pair appeared 5 sec. later.

Each stimulus pair consisted of the standard shape (see Fig. 1) and one other. On the "S" trials both shapes were the standard. On the "D" trials the standard was always on the left and, on the right, was either (*a*) one of the five shapes used in the predifferentiation training or (*b*) one of another group of very similar shapes previously unseen by *S*. The shapes referred to in (*a*) are labeled C_1 through C_5; those mentioned in (*b*) are C_6 through C_{10}.

Each *S* was given 60 "D" trials and 30 "S" trials. The "D" trials were divided into 30 on which shapes C_1–C_5 were used, and 30 on which C_6–C_{10} were used. Thus, the standard was paired with each of the other shapes six times and with itself 30 times. None of the *S*s had seen either the standard or stimuli C_6–C_{10} before the beginning of the discrimination task. For both Group C and Group A the mean elapsed time between the completion of predifferentiation training and beginning the discrimination task was about 5 min.

The discrimination task was the same for all groups. These groups differed from each other only in their prediscrimination experience.

Results

Predifferentiation training.—Performance on the ten paired-associate learning trials was scored by counting the number of errors made on the last two trials (ten items). Table 1 shows that both groups were making close to 70% correct responses by the end of the learning session, with Group C making slightly fewer errors.

Discrimination task.—Performance on the simple discrimination task was scored in terms of accuracy and latency of the responses. Since "S" and "D"

TABLE 1

PRELIMINARY LEARNING TASK

Group	N	Errors on Last Two Trials		t
		Mean	SD	
C	100	2.95	2.05	1.10
A	100	3.29	2.33	

trials were scored separately, there were four performance measures obtained: "S" latency, "D" latency, "S" accuracy, and "D" accuracy. The latency measures were based only on those trials on which *S* made the correct response.

Mean scores obtained by the three groups on each of these four measures are shown in Table 2. It can be seen that the differences between the group mean scores on each measure are small, and that no systematic trends are apparent. Statistical test showed that none of the differences between the group means are significant at the .05 level.

A further breakdown of the results based on shapes C_1–C_5 and shapes C_6–C_{10} failed to reveal any significant differences between Groups C and A as a function of the particular stimuli used.

In general, then, it appears clear that no facilitation of simple discrimination occurred as a result of predifferentiation training in this experiment. Paired-associate training using the stimuli later to be discriminated did not result in significantly better performance than similar training using different stimuli. Furthermore, neither of these kinds of training resulted in better discrimination performance than no training at all.

Level of previous training.—It might reasonably be argued in this kind of experiment that positive transfer from a pretraining task to a criterion task would be a function of the level of proficiency attained on the earlier task. This argument would be pertinent here, since *S*s were given a standard number of paired-associate learning trials instead of being carried to some predetermined level of proficiency. If positive transfer could be expected only after a minimum level of proficiency had been attained, then it could well be true that significant differences among the groups failed to appear because an insufficient number of *S*s reached the minimum level required.

As a means of checking on this possibility, Groups C and A were each divided into four approximately equal subgroups based on learning scores,

TABLE 2

LATENCY AND ACCURACY OF DISCRIMINATION RESPONSE

Measure*	Predifferentiation Training				Control	
	Group C		Group A		Group NP	
	Mean	SD	Mean	SD	Mean	SD
"S" Latency	19.16	6.19	19.88	7.21	19.52	7.78
"D" Latency	14.11	3.46	14.35	3.69	13.89	3.98
"S" Accuracy	27.68	2.58	27.84	2.92	27.40	2.90
"D" Accuracy	29.58	0.91	29.45	0.95	29.38	1.08

* Latencies were measured in units of .001 min. Accuracy scores were based on the number of correct responses in 30 trials.

TABLE 3

CORRECT RESPONSES IN 30 TRIALS FOR SUBGROUPS SELECTED ON THE BASIS OF LEARNING SCORES

Subgroup Learning Score	Group C					Group A				
	N	"S" Accuracy		"D" Accuracy		*N*	"S" Accuracy		"D" Accuracy	
		Mean	*SD*	Mean	*SD*		Mean	*SD*	Mean	*SD*
0–12	22	28.23	2.26	29.60	1.52	26	28.04	1.99	29.45	1.00
13–16	28	27.32	2.78	29.35	2.05	24	28.08	1.82	28.00	2.83
17–19	20	27.90	2.07	29.00	2.06	26	27.96	2.71	29.25	2.16
20–25	30	27.47	3.15	29.80	0.98	24	27.21	4.39	29.70	1.17

and these subgroups were compared on the basis of discrimination accuracy. In this analysis each *S*'s learning score was based on the number of correct responses made during the last half of the learning session, the range of possible scores being from zero to 25. Table 3 shows that there was essentially no difference between any pair of C and A subgroups, indicating no advantage for specific rather than nonspecific learning at any level of pretraining. Also, there were no apparent differences among any of the means for a given group, indicating that the level of pretraining was irrelevant to discrimination performance in this simple-discrimination problem.

The original conclusion, therefore, remains unchanged. In this experiment ten trials of predifferentiation training did not produce a significant change in accuracy or latency of simple discrimination.

EXPERIMENT II

Experiment II was the same as Exp. I with regard to the predifferentiation training, but a different discrimination task was utilized. The stimuli were presented one at a time in a tachistoscope; on each trial *S* was required to identify the stimulus by selecting it from the entire group of five. Thus, the task was one of multiple discrimination in a multiple-choice response situation.

Method

Apparatus.—The apparatus used in the predifferentiation training was the same as in Exp. I, and the stimuli shown in Fig. 1 and Fig. 2 likewise were used, with the exception that the "standard" shape shown in Fig. 1 was not used.

In the discrimination task the stimuli were presented by means of an electronically-controlled Dodge-type tachistoscope. This device was equipped to present visual stimuli at selected exposures ranging from 2.5 to 500 msec. The pre- and postexposure field was equated in brightness with the exposure field at the point of *S*'s eyes. The stimulus shapes were printed on 8 × 10-in. cards which were inserted into the side of the machine corresponding to the exposure field. In the side corresponding to the pre- and postexposure field the five shapes appeared in small images ½ in. high along the bottom edge of an otherwise plain white 8 × 10-in. card. The shapes appeared in the same order from left to right as the five keys used in making the response. The keys were set in a row on the table in front of *S* and below the level of the tachistoscope eyepiece. The purpose of this arrangement was to avoid any errors resulting from accidentally pressing a key other than the one intended. Each key was connected to a corresponding light in a panel on the control table where the responses were recorded.

Subjects.—The *S*s were 190 basic airmen at Lackland Air Force Base. They were assigned at random to the various experimental groups.

Predifferentiation training.—The procedure for the learning session was the same as in Exp. I. Each *S* was allowed to study the paired associates for 2 min. before receiving ten trials on the exposure device. Group C consisted of 71 *S*s who received predifferentiation training on the

TABLE 4

PRELIMINARY LEARNING TASK

Group	N	Errors on Last Two Trials		t
		Mean	SD	
C	71	2.78	2.26	1.75
A	75	3.48	2.52	

shapes shown in Fig. 1. Group A consisted of 75 *Ss* who were trained on the shapes shown in Fig. 2. The control group (NP) consisted of 44 *Ss* who received no pretraining before being given the discrimination task. For Groups C and A the mean elapsed time between the completion of predifferentiation training and beginning the discrimination task was less than 7 min.

Discrimination task.—The *S* was seated in front of the tachistoscope and instructed to respond after each observation by pressing the key corresponding to the shape which appeared in the exposure field. No attempt was made to hurry *S* in his response; rather, the importance of accuracy was emphasized.

On each observation the stimulus field of *S* consisted initially of the white card bearing small pictures of the stimulus shapes along its bottom margin. After the command, "Ready," this field was replaced briefly by a larger (3 in. high) picture of one of the five shapes. As soon as this picture disappeared, the first reappeared, and *S* was required to decide which of the five shapes he had seen and press the appropriate key.

Every *S* made six observations of each of the five shapes at each of seven exposures, making a total of 210 observations per *S*. The exposure times used were 2.5, 5, 10, 20, 30, 50, and 100 msec. Performance was measured in terms of the total number of correct identifications of all stimuli at all exposures.

Results

Predifferentiation training.—Performance scores on the ten trials of paired-associate learning were obtained in the same way as in Exp. I, and are shown in Table 4. Group A again made slightly more errors than Group C but, as before, both groups were making close to 70% correct responses by the end of the training session.

Discrimination task.—Performance on the multiple discrimination task was scored initially in terms of the number of correct identifications made at each exposure time. Table 5 shows that accuracy of identification increased rapidly for all groups up to an exposure time of 20–30 msec.: thereafter, no further change occurred up to an exposure time of 100 msec., the longest exposure time used. It is interesting to note that, in this apparatus, the critical duration for the time-intensity relation for perceived brightness would occur at about 20–25 msec. (1). It would seem reasonable, therefore, to conclude that the poorer

TABLE 5

ACCURACY OF MULTIPLE DISCRIMINATION (CORRECT RESPONSES IN 30 TRIALS)

Group	N	Measure	Duration of Exposure in Milliseconds						
			2.5	5.0	10	20	30	50	100
C	71	Mean	10.84	14.54	18.26	20.00	20.43	20.94	21.10
		SD	3.75	4.45	4.79	4.37	4.59	4.02	4.63
A	75	Mean	9.72	14.40	17.67	19.45	19.84	20.53	19.84
		SD	3.18	4.15	4.04	3.80	4.41	3.75	4.05
NP	44	Mean	11.37	14.96	18.35	20.09	20.59	20.98	20.52
		SD	3.56	3.76	4.36	4.54	4.37	4.04	4.22

accuracy of identification at exposures less than the critical duration was primarily due to the diminution of brightness throughout this range of exposures. Of particular interest for this experiment is the fact that the performances of the three groups differed hardly at all. Not only was there no discernible advantage for the group receiving specific training over the group receiving nonspecific training, there was no advantage for either

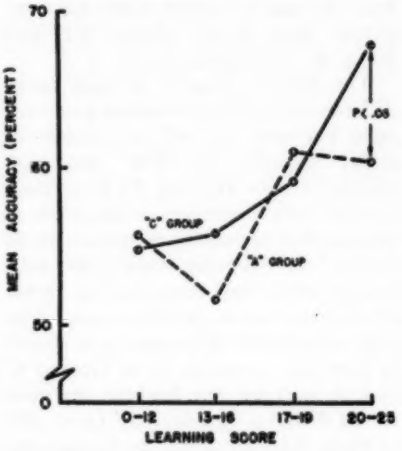

FIG. 3. Accuracy of multiple discrimination shown as a function of the level of proficiency achieved on the pretraining task. The difference between the C and A subgroups achieving the highest level of proficiency is significant at the .05 level.

trained group over a group having no previous experience with the stimuli.

The differences between the groups were tested by obtaining mean values at all exposure times combined. The results of applying the t test to the differences between these means showed that none of the differences achieved significance at the .05 level of confidence.

Level of previous training.—As was done in Exp. I, a check was made to see whether the amount of transfer from the predifferentiation training to the discrimination task was a function of the level of proficiency attained on the preliminary task. Groups C and A were divided into subgroups on the basis of learning scores and compared on the basis of discrimination performance. The results of this analysis are shown in Fig. 3. Unlike Exp. I, in this analysis there is a consistent increase in discrimination accuracy in Group C as a function of proficiency on the paired-associate task. This result, by itself, is consistent with our hypothesis. However, although Group A shows no such consistent change, the only significant difference ($p < .05$) between the mean performance scores occurred in the subgroups achieving between 80% and 100% accuracy on the last 25 items of the learning task.[2] At best, these results could be interpreted as suggesting the possibility that intensive predifferentiation training might result in a significant amount of positive transfer to a multiple-discrimination task.

DISCUSSION

Although Gibson's predifferentiation hypothesis was developed in connection with problems of verbal learning (5), a legitimate extension of the hypothesis is that predifferentiated stimulus items should be more quickly and accurately discriminated from one another than unfamiliar items. This interpretation is supported by the fact that Gagné and Baker (4) obtained positive transfer from verbal pretraining to a simple discrimination-reaction task. However, the Gagné and Baker study, as well as other studies reporting transfer of predifferentiation training (8, 14), failed to control the possibility of transfer in terms of factors not specific to the stimuli, such as "warm-up" or "learning-how-to-learn." In the present study positive transfer, had it occurred, would have had to be attributed to factors specific to the stimulus items themselves.

[2] According to Wilkinson's Tables (18), the probability is .1855 that this t could have occurred by chance.

In these two experiments the predifferentiation hypothesis would have been supported only if Group C had performed significantly better than Group A on the discrimination task. This occurred unequivocally in neither experiment. In addition, neither Group A nor Group C performed significantly better than a control group which received no pretraining whatsoever. A significantly poorer performance by Group NP would have indicated the operation of factors such as "warm-up" or "learning-how-to-learn." The failure of this result to occur is probably attributable to the great dissimilarity between the pretraining task and the criterion task. It is clear, though, that no positive transfer occurred on the basis of factors specific to the stimulus items, suggesting that the positive transfer obtained in other predifferentiation experiments may have been due to nonspecific factors.

On the other hand, the failure of positive transfer to occur on any basis is somewhat surprising in light of the many demonstrations of the principle that experiential factors may affect perception. In recent years perceptual thresholds have been shown to vary as a function of interest (13), meaning (10), familiarity (15), motivation (7), set (12), and economic status (2). Furthermore, in Exp. II a significant difference was found between two subgroups which had performed best on the predifferentiation task. Of particular interest in this regard is an experiment by Vanderplas (17), who found a significant reduction in the thresholds of nonsense words which had been paired with geometrical shapes during pretraining. He found that a group which overlearned during the pretraining had significantly lower thresholds than a group which only learned to a criterion. It may be that a certain amount of overlearning is necessary for the predifferentiation effect to manifest itself. If so, definite conclusions about the effect of verbal predifferentiation on shape discrimination must await further research involving the use of greater amounts of pretraining.

Summary and Conclusions

An attempt was made to extend the predifferentiation hypothesis from the field of verbal learning to shape discrimination. The major hypothesis of this experiment was that verbal pretraining would result in a change in the speed and accuracy of shape discrimination.

In two experiments *S*s were given verbal predifferentiation training on nonsense shapes and then given a shape-discrimination test. In Exp. I they were required to discriminate the five learned shapes from a standard shape by responding "Same" or "Different." In Exp. II the five learned shapes were exposed singly in a tachistoscope, and *S* was required to indicate which shape had appeared. In each experiment there were three groups. Group C was given ten trials of paired-associate training on the five shapes used in the discrimination task. The pretraining for Group A was the same, except that different shapes were used. Group NP was given no pretraining at all.

The results showed no significant differences in discrimination performance between any of the groups in either experiment. The two pretrained groups (C and A) were then divided into subgroups on the basis of the number of correct responses made during the learning task; the subgroups were then compared in terms of discrimination performance. The only significant difference was found in Exp. II, in which *S*s in Groups C and A making the highest learning scores differed significantly ($p < .05$) in their discrimination performances.

The main conclusion of this study was that the major hypothesis was not supported. The one significant difference obtained suggests that the predifferentiation effect might appear if more intensive pretraining were given.

(Received September 12, 1952)

References

1. Arnoult, M. D. Accuracy of shape discrimination as a function of the range of exposure intervals. San Antonio, Texas: Human Resources Research Center, Lackland Air Force Base, December 1951. (*Research Bulletin* 51–32.)
2. Bruner, J. S., & Goodman, C. C. Value and need as organizing factors in perception. *J. abnorm. soc. Psychol.*, 1947, **42**, 33–44.

3. French, R. S. Number of common elements and consistency of reinforcement in a discrimination learning task. *J. exp. Psychol.*, 1953, **45**, 25–34.
4. Gagné, R. M., & Baker, K. E. Stimulus pre-differentiation as a factor in transfer of training. *J. exp. Psychol.*, 1950, **40**, 439–451.
5. Gibson, E. J. A systematic application of the concepts of generalization and differentiation to verbal learning. *Psychol. Rev.*, 1940, **47**, 196–229.
6. Harlow, H. F. The formation of learning sets. *Psychol. Rev.*, 1949, **56**, 51–65.
7. Holston, R. P. Some effects of motivation on visual discrimination. *Amer. Psychologist*, 1951, **6**, 318. (Abstract.)
8. Hovland, C. I., & Kurtz, K. H. Experimental studies in rote-learning theory: X. Pre-learning syllable familiarization and the length-difficulty relationship. *J. exp. Psychol.*, 1952, **44**, 31–39.
9. Irion, A. L. The relation of "set" to retention. *Psychol. Rev.*, 1948, **55**, 336–341.
10. McGinnies, E. Emotionality and perceptual defense. *Psychol. Rev.*, 1949, **56**, 244–251.
11. Noble, C. E. An analysis of meaning. *Psychol. Rev.*, 1952, **59**, 421–430.
12. Postman, L., & Bruner, J. S. Multiplicity of set as a determinant of perceptual organization. *J. exp. Psychol.*, 1949, **39**, 369–377.
13. Postman, L., Bruner, J. S., & McGinnies, E. Personal values as selective factors in perception. *J. abnorm. soc. Psychol.*, 1948, **43**, 142–154.
14. Rossman, I. L., & Goss, A. E. The acquired distinctiveness of cues: The role of discriminative verbal responses in facilitating the acquisition of discriminative motor responses. *J. exp. Psychol.*, 1951, **42**, 173–182.
15. Solomon, R. L., & Howes, D. H. Word frequency, personal values, and visual duration thresholds. *Psychol. Rev.*, 1951, **58**, 256–270.
16. Thune, L. E. The effect of different types of preliminary activities on subsequent learning of paired-associate material. *J. exp. Psychol.*, 1950, **40**, 423–438.
17. Vanderplas, J. M. Frequency of experience versus organization as determinants of visual thresholds. Unpublished doctor's dissertation, Univer. of Texas, 1951.
18. Wilkinson, B. A statistical consideration in psychological research. *Psychol. Bull.*, 1951, **48**, 156–158.

Journal of Experimental Psychology
Vol. 45, No. 6, 1953

THE ROLE OF IRRELEVANT DRIVE STIMULI IN LEARNING[1]

SEYMOUR LEVINE
New York University[2]

It has been reported by Hull (4) and Leeper (9) that rats are able to acquire differential habits on the basis of internal stimulation. Both of these studies revealed that the animals could learn to make one turning response when hungry and another response when thirsty. To explain these results Hull assumed that the animals learned to respond to *two different stimulus patterns*, incorporating into these stimulus patterns the hunger drive stimulus and the thirst drive stimulus. The implication of Hull's position is that the relevancy of the drive stimulus *does not* influence the capacity of the drive stimuli in acquiring associative strength.

Kendler has presented an alternative hypothesis called the *selective principle* which states "that only those drive stimuli which are themselves reduced become connected to a rewarded response" (6, p. 217). This hypothesis was proposed in order to explain the finding that rats, after having been run while simultaneously hungry and thirsty in a T maze which had food in one end box and water in the other were able to choose the appropriate side on test trials when either hungry or thirsty. These results were contrary to Hull's analysis, insofar as both drive stimuli should have become associated to the right- and left-turning response, since both the hunger and thirst drive stimuli were present during training. If this did occur, chance behavior would have been expected when *S*s were made either hungry or thirsty during the test trials.

Several experiments have been reported recently that tend to support Kendler's hypothesis of selective association of drive stimuli. Kendler and Law (8) trained animals in a T maze to choose the side leading to food. One group was motivated by hunger while the other was simultaneously hungry and thirsty. Following the attainment of the criterion of learning *S*s in each group were trained to reverse their spatial response. This was accomplished by making *S*s thirsty and placing water in the previously empty end box. According to Hull's nonselective position, it should be expected that *S*s who were hungry and thirsty during training would be retarded in learning the test problem. This would follow because the thirst drive stimulus during the test trials for these *S*s would tend to evoke the correct response of the training series, which would be incorrect for the test series. The results of this study revealed no differences between the two groups in reaching the criterion of learning in the test problem. A similar study in which thirsty *S*s and thirsty and hungry *S*s were trained to go to water in one goal box and then trained, during a test series, to go to food when hungry, produced the same general results, i.e., no difference between the groups during the test series. Since both studies found no evidence of an irrelevant drive stimulus becoming associated, the data were interpreted to be consistent with the selective principle. Further studies by Webb (12) and Kendler (7) also tend to support the hypothesis of the selective principle of association of drive stimuli.

Amsel (1), however, has recently provided evidence which he has interpreted to be contradictory to Kendler's hypothesis. In Amsel's experiment *S*s were required to learn to choose one arm of a T maze to reach an anxiety-reducing goal box when under one irrelevant drive state (hunger) and the alternative arm under a different irrelevant drive state (thirst). Because the only basis for the discrimination is provided by the irrelevant drive conditions, evidence of learn-

[1] This paper is a portion of a thesis submitted to the Department of Psychology of New York University in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The writer is indebted to Professor Howard H. Kendler for his advice and assistance throughout all the phases of this investigation.

[2] Now at Boston University.

ing would, according to Amsel, tend to contradict the selective principle. Two of Amsel's ten *Ss* reached the learning criterion (ten successive correct first choices) before training was discontinued, and the group as a whole tended to respond above the 50% level. On the basis of these results Amsel concluded ". . . considering the performance . . ., one might, therefore, be led to modify Kendler's hypothesis thus: irrelevant drive stimuli (of the hunger and thirst type) become connected to rewarded responses with which they are contiguous only as a result of considerable practice" (1, p. 795). Amsel further concludes that insofar as some learning was evidenced, the selective principle was not supported.

Amsel's data, however, do not justify the rejecting of the selective principle of association of drive stimuli. Having only two of ten *Ss* demonstrate learning is not convincing data. This is particularly true when a learning criterion of ten successive correct responses is selected without considering the number of trials in the test series. Grant (3) has pointed out that, as the number of trials in a series is extended, the probability of a given combination occurring in the series approaches chance. In addition to the above it should be mentioned that Amsel tended to vary the hunger and thirst drives on alternate days. There would exist a possibility that his *Ss* were responding to a single alternation pattern. Finally, and probably the most important point of all, is that the data, upon which the selective principle of association of drive stimuli was based, involved primary drives for both the relevant and irrelevant drives. The possibility exists that the learned drive of anxiety operates in a special manner which is not characteristic of primary drives, and possibly other secondary drives.

The present investigation provides two experimental situations designed to test the selective principle of association of drive stimuli. The first study provides a situation in which the only differentiating stimuli in a spatial discrimination problem are irrelevant drive stimuli, one resulting from water deprivation, the other from food deprivation. The experimental conditions consist essentially of training white rats to push one of two panels to remove a light stimulus. On days when *S* is hungry, a response to the right panel will result in the immediate removal of the light; on days when *S* is thirsty, pushing the left panel will result in the immediate removal of the light.

If there is failure to learn on the basis of the irrelevant drive stimuli, then the hypothesis of selective association would be supported. If there is evidence of learning on the basis of the irrelevant drive stimuli, then the selective principle would be invalidated. Winnick (14) reports the results of a study similar in design, which she interprets to be inconsistent with the selective principle. Her experiment, which was designed for another purpose, did not control all the variables and consequently, as she implies, the results in respect to the selective principle were not entirely definitive.

The second study provides an experimental situation similar to that used in the study of Kendler and Law (8). If, as Amsel believes, the major variable in the association of drive stimuli is that of "considerable practice," then perhaps one of the reasons Kendler (6), Kendler and Law (8), and Webb (12) failed to reveal evidence of the association of irrelevant drive stimuli to rewarded responses is that *Ss* did not receive sufficient practice. The purpose of the second study in this investigation is to furnish an experimental design to conform to the requirements necessary to test Amsel's suggestion that considerable practice is necessary. In this experiment four groups of rats are trained to go to that side of a T maze which contains either food or water. Two groups are simultaneously hungry and thirsty while the two other groups are either hungry or thirsty. After reaching the end of the training period (in this experiment training is stopped after the *Ss* have reached a criterion of 90 reinforced trials), the groups which have been reinforced with food during training

are made thirsty, and the groups which received water during training are made hungry. Food or water is placed in the end box which had previously been empty. According to a *nonselective* principle of association of drive stimuli, the groups which were simultaneously hungry and thirsty during training should be retarded in learning to go to food or water during the test trials because the irrelevant drive stimulus should have a tendency to evoke the responses to the previously reinforced side. The selective principle, however, would predict no retardation for the reason that the irrelevant drive stimulus would not become connected to the spatial response leading to reinforcement.

Experiment I

Subjects.—The *S*s were 11 naive male albino rats purchased from the Albino Farms in Red Bank, New Jersey. They were between 80 and 100 days old at the start of the experiment.

Apparatus.—The entire apparatus as shown in Fig. 1 consisted of a box 9 in. in length and $8\frac{3}{16}$ in. high. The box was built at an angle so that at the apex of the box the width was $6\frac{1}{2}$ in., and at the place where the panels were located the width was $13\frac{1}{2}$ in. The purpose of this was to reduce the random movements of *S*s and to direct *S*s' movements toward the panels. The panels were $3\frac{1}{2}$ in. wide and $7\frac{1}{2}$ in. high. The apparatus was built of $\frac{1}{4}$-in. plywood.

The light stimulus was provided by a 150-w. clear bulb suspended 6 in. above the apparatus. The box was covered with opaque $\frac{1}{4}$-in. Plexiglas. The frosted Plexiglas served to diffuse the light throughout the entire box giving equal illumination throughout the apparatus.

The interior of the box was painted a flat gray, with the right panel painted a flat black and the left panel a flat white.

The apparatus was wired so that when the correct panel was pushed, the panel made contact with a microswitch located directly behind the panel. This microswitch closed the circuit and the light was turned off instantaneously. A microswitch was located behind each of the two panels. The panel had to be pushed approximately $\frac{1}{4}$ in. before the microswitch closed. Both panels required the same amount of pushing. A Standard Electric Time clock was connected to the circuit so that when the light was turned on, the clock was started, and when the circuit was broken, the clock stopped.

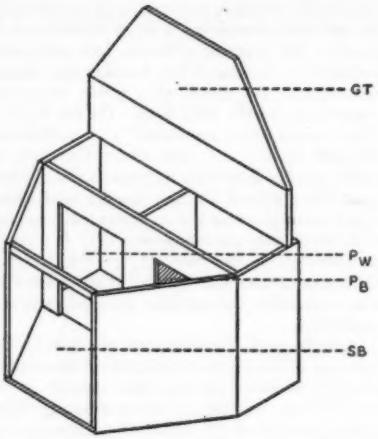

Fig. 1. Ground plan of apparatus: *SB*—starting box; *PB*—black panel; *PW*—white panel; *GT*—Plexiglas top.

Through the use of a control box, *E* could select which panel would, when pushed, turn off the light. On any single day only one panel could serve to remove the stimulus. If the incorrect panel was pushed, the clock stopped but the light remained on. The *S* could then turn the light off by pushing the correct panel.

Procedure.—All *S*s were trained in the discrimination apparatus with irrelevant drive stimuli as the basis for discrimination. The *S*s were run five trials a day for 90 days, yielding a total of 450 trials under the conditions of hunger or thirst.

The procedure on the first and subsequent experimental days was identical except for the changes in the motivational conditions within the groups. Each *S* was placed in the discrimination apparatus and allowed to remain there for 5 sec. with the light turned off. The apparatus was situated in a lightproof room. The only other light in this room aside from the light stimulus was a frosted 5-w. bulb used to provide light for the clock and control panel. This light was well shielded from the apparatus so that for all practical purposes the room was in complete darkness. After the 5 sec. elapsed, the light was turned on by *E*. Since a correction technique was employed, every trial ended with the removal of the light stimulus. The *S*s were allowed to remain in the box for 15 sec. following the successful completion of each trial. After the 15-sec. period *S* was removed from the box and returned to the carrying cage. A period of at least 5 min. elapsed between trials.

On days when *S*s were hungry, pressing the right (black) panel resulted in removal of the

light. On days when *S*s were thirsty, pressing the left (white) panel resulted in turning off the light.

The drive stimuli, both thirst and hunger, were based on 21 to 24 hr. of food or water deprivation. The specific details of the maintenance schedule for the hunger and thirst days for this experiment and the subsequent one are contained in the original thesis (10).

On any given day of the experimental sequence, half the *S*s were thirsty while the other half were hungry. The hunger and thirst days were presented in random order with the precaution taken that there would be no more than three successive days under one motivational condition.

Results.—The learning curve is shown in Fig. 2. In this analysis and all other subsequent analyses, only the first trial of each day was used as the index of learning. The curve shows the percentage of correct responses of the group for successive blocks of six first trials. Each point is, therefore, the percentage of correct responses out of a possible 66 in a block.

Examination of this curve reveals that at about the thirteenth block of trials the curve appears to have leveled off at about 75% correct responses. An interesting feature of this curve is that no single point is below chance. Such data would imply that learning, although incomplete, occurred on the basis of irrelevant drive stimuli.

An examination of the data of individual *S*s supports the same conclusion. The 90 daily first trials of each *S* were divided into three sections of

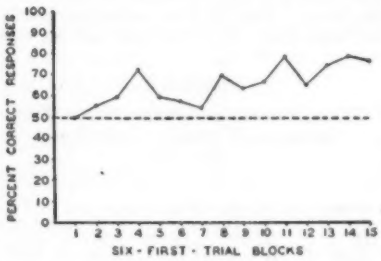

FIG. 2. Curve showing learning of panel pushing response

TABLE 1

NUMBER OF CORRECT RESPONSES DURING LEARNING TRIALS

S	Trials				χ^2	*p*
	1–30	31–60	61–90	Total		
1	18	19	24	61	11.37	.001
2	14	21	20	55	4.44	.05
3	17	18	24	59*	10.68	.01
4	15	17	30	62*	12.86	.001
5	17	13	12	42	.40	—
6	24	26	27	77*	45.51	.001
7	18	19	19	57	6.40	.02
8	20	16	19	55	4.44	.05
9	17	18	23	58	7.52	.01
10	18	20	26	64*	16.04	.001
11	19	21	28	68*	23.53	.001

* Reached criterion of 12 (or more) successive correct trials.

30 trials. The number of correct responses within each of the 30-trial blocks was computed for each *S*. The information is shown in Table 1.

The data which were used to determine the level of performance for each *S* were the number of correct responses out of the total possible 90 correct responses. The use of a χ^2 formula for approximating the binomial by a method suggested by Grant (2) indicated that a deviation as large as 10 from the expected chance score of 45 correct out of 90 would be significant at the .05 level of confidence, and that a deviation of 13 would be significant at the .01 level, and a deviation of 15 (or more) would be significant at the .001 level.

An examination of Table 1 reveals that in only one case (*S* 5) was there a negative deviation. In all other cases there was a significant positive deviation from chance expectation; seven *S*s responding beyond the .01 level of confidence. A test presented by Wilkinson (13) reveals that the probability of obtaining seven probabilities greater than the .01 level in a total of 11 is significant well beyond the .01 level of confidence.

Although no specific criterion of

learning was decided upon prior to the experiment, it is interesting to note that five out of the 11 *Ss* ran 12 or more successive correct choices, and that *S* 4 ran the last 30 trials correctly. According to the tables presented by Grant (3), a run of 12 successive correct responses in a total of 90 choices where the probability of a correct response is .5 is significant at the .01 level. Obtaining five "significances" at the .01 level out of 11 statistics is in itself significant well beyond the .01 level.

Experiment II

First Study

Subjects.—The *Ss* were 32 naive male albino rats purchased from the Albino Farms, Red Bank, New Jersey. They ranged in age from 90 to 100 days.

Apparatus.—A single choice-point T maze, similar to the one used by Kendler (6) was used.

Procedure.—The *Ss* were randomly divided into two groups of 16 animals. For approximately one week prior to the experiment each *S* was handled for about 3 min. a day to reduce emotionality. The preliminary training consisted of placing five *Ss* in the maze at one time and allowing a period of free exploration for 1 hr. During this time all the doors of the maze were opened and both end boxes were empty. On the following day the experiment proper began. Group H (hungry) was deprived of food for 22 hr. while Group H&T (hungry and thirsty) was deprived of food and water for the same period of time. Food, in the form of 15 pellets of Purina Laboratory Chow, was present in the end box of the right arm of the maze. The other end box remained empty although 15 pellets of food were placed around the outside of the box to control for olfactory cues.

Although the major groupings were made according to the motivational state of the *Ss*, under each of these groupings there were two subgroups. For eight *Ss* in Groups H and H&T, each *S* was given five free trials daily. The other eight *Ss* in each group were given three free-choice correct trials daily. The procedure used for these *Ss* was to give them three free-choice trials daily, and if any errors were made, the *Ss* were given forced trials to the correct side so that the total number of daily reinforcements would always be three. The purpose of this procedure was to provide equal number of reinforcements for *Ss* in both the H and H&T groups on any single day, and in turn provide equal experience during the learning of the first problem both in number of reinforcements and number of days run.

All *Ss* were run until the criterion of 90 reinforcements was achieved. For the groups that were run five trials daily, this criterion was reached in about 20 days. For the groups run three reinforced trials daily, 30 days were needed before the criterion was attained. When *S* chose the correct side, it was allowed to eat for 20 sec.; when it chose the wrong side, it was kept in the empty end box for 30 sec. At least 15 min. elapsed between successive trials of the same *S*.

Test trials.—Following the attainment of the criterion, *Ss* of both groups were made thirsty and trained to go to the side opposite to the one in which they received food, i.e., the previously empty end box. Water in a glass coaster was made available in the previously empty end box.

During the learning of the second problem all *Ss* were run 3 free-choice trials daily until a criterion of four successive days of correct trials (12 successive trials) was reached. When making the correct choice, *Ss* were permitted to drink for 10 sec.; following an incorrect choice they were kept in the empty end box for 30 sec. If *S* failed to learn the second problem during a period of ten days, its running was discontinued.

Second Study

Subjects.—The *Ss* in this study were 32 naive male albino rats purchased from the Albino Farms, Red Bank, New Jersey. At the beginning of the experiment their ages ranged from 80 to 120 days.

Apparatus.—The apparatus was identical to that used in the first study.

Training trials.—The experimental procedure was similar to that used in the first study, except for the motivational conditions of *Ss* and the reward used. One end box contained a glass coaster filled with water while the other end box remained empty. Group T was motivated by 22 hr. of water deprivation, while Group T&H had 22 hr. of water and food deprivation.

In this training series the same subdivisions were made within each group as were made in the first study. Half the *Ss* in each group ran five free trials daily, while the other half ran three

TABLE 2

Mean Number of Errors during Test Series (to Water) of First Study (Exp. II)

Group	*N*	Mean	σ	*Z*
H	16	2.06	2.26	5.32*
H&T	16	13.31	7.91	

* Significant at the .001 level.

TABLE 3

MEAN NUMBER OF ERRORS TO CRITERION OF LEARNING DURING TEST TRIALS (TO FOOD) OF SECOND STUDY (EXP. II)

Group	*N*	Mean	σ	*Z*
T	16	2.06	1.70	5.40*
T&H	16	16.81	7.11	

* Significant at the .001 level.

free trials daily and as many forced trials per day as were necessary to result in a total of three reinforcements daily. The *S*s were allowed to drink for 10 sec. following a correct response and were restricted in the empty end box for 20 sec. following an incorrect response. All *S*s were run to a criterion of 90 reinforced trials.

Test trials.—On the day following the attainment of the criterion the *S*s were motivated by a hunger drive based upon 22 hr. of food deprivation and were satiated for water.

The procedure for running the test series for Groups T and T&H was the same as that used in the first study with the exception that if *S* made a correct choice, it was permitted to eat for 20 sec. If an incorrect response was made, *S* was detained for 30 sec. in the empty end box.

Results.—The major results of this experiment are presented in Tables 2 and 3.

In both studies it was found that *S*s whose drive state during training was simultaneous hunger and thirst were considerably retarded in learning the problem during the test series. A *U* test (11) which makes no assumptions about the nature of the distributions from which the means are calculated, indicates the difference between the mean number of errors for the groups in both studies to be significant beyond the .001 level of confidence.[3]

These results tend to be in agreement with the expectations of the nonselective principle and at variance with the implications of the selective principle.

DISCUSSION

The results of these experiments clearly contradict the hypothesis of selective association of drive stimuli and support the position maintained by Amsel (1), namely, that irrelevant drive stimuli acquire associative strength only as a result of considerable practice.

In the first experiment it was demonstrated that an irrelevant drive stimulus could become a cue in a simple discrimination situation. In the second experiment it was shown that the learning of a new spatial response in a T maze was retarded because the relevant drive stimulus had been conditioned as an irrelevant drive stimulus to the side opposite the one *S* was now required to learn.

It thus appears that the major variable in the association of irrelevant drive stimuli is that of considerable practice. Amsel explains the necessity of considerable practice by maintaining that drive stimuli of the hunger and thirst type acquire associative strength slowly. This occurs because the presentation of such stimuli usually precedes the experimental situation by many hours, and according to Hull's principle of the dynamic state of stimuli (5, p. 207) the capacity of a stimulus to acquire associative strength decreases as the time of action of the stimulus upon the receptor mechanisms increases.

SUMMARY

The present experiments attempted to evaluate the hypothesis that drive stimuli, not themselves reduced by a goal object, do not become connected to the rewarded responses with which they are contiguous.

Two experiments were performed. The first involved the learning of a

[3] Although there were slightly different procedures used during training for half the *S*s in each group, analysis of the data revealed no differences in performance between the different subgroups. The total group was used in the analysis of the data.

spatial discrimination on the basis of a discrimination between two irrelevant drive conditions, one resulting from water deprivation, and the other from deprivation of food. Both responses (pushing a left or right panel) resulted in the same reward, light avoidance. Insofar as most *Ss* learned in this situation the selective principle was not supported.

The second experiment involved two studies. In the first study Group H (hungry) and Group H&T (hungry and thirsty) were trained in a single-unit T maze to choose the side leading to food (training series). Following the attainment of a criterion (90 reinforcements), *Ss* in each group were trained to respond to the other side of the maze to get water (test series). During the test series both groups were thirsty. The second study was similar to the first except that during the training trials *Ss* were motivated either by thirst (Group T), or thirst and hunger (Group T&H). In the test series the prevailing motivation was hunger, and food was placed in the previously empty goal box.

Significant differences were obtained between the groups, in both studies, in reaching the criterion of learning during the test series. In both studies the groups trained under hunger and thirst motivation were significantly retarded in learning the new response during the test series.

These experiments were interpreted to be inconsistent with the selective principle of association of drive stimuli and consistent with the position taken by Amsel, that *considerable practice* is necessary before irrelevant drive stimuli become connected to rewarded responses with which they are contiguous.

(Received October 13, 1952)

References

1. Amsel, A. Selective association and the anticipatory goal response mechanism as explanatory concepts in learning theory. *J. exp. Psychol.*, 1949, **39**, 785–800.
2. Grant, D. A. New statistical criteria for learning and problem solutions in experiments involving repeated trials. *Psychol. Bull.*, 1946, **43**, 272–281.
3. Grant, D. A. Additional tables of the probability of "runs" of correct responses in learning and problem solving. *Psychol. Bull.*, 1947, **44**, 276–279.
4. Hull, C. L. Differential habituation to internal stimuli in the albino rat. *J. comp. Psychol.*, 1933, **16**, 255–273.
5. Hull, C. L. *Principles of behavior.* New York: D. Appleton Century, 1943.
6. Kendler, H. H. The influence of simultaneous hunger and thirst drives upon the learning of two opposed spatial responses of the white rat. *J. exp. Psychol.*, 1946, **36**, 212–220.
7. Kendler, H. H. An experimental test of the non-selective principle of drive stimuli. *Amer. J. Psychol.*, 1949, **62**, 382–391.
8. Kendler, H. H., & Law, F. E. An experimental test of the selective principle of association of drive stimuli. *J. exp. Psychol.*, 1950, **40**, 299–304.
9. Leeper, R. The role of motivation in learning: a study of the phenomenon of differential motivational control of the utilization of habits. *J. genet. Psychol.*, 1935, **46**, 3–40.
10. Levine, S. An experimental analysis of the selective principle of association of drive stimuli. Unpublished Ph.D. thesis, New York Univer., 1952.
11. Mann, H. B., & Whitney, D. R. On a test of whether one of two random variables is stochastically larger than the other. *Ann. math. Stat.*, 1947, **18**, 50–60.
12. Webb, W. B. An experimental study of the role of an irrelevant drive in the behavior of the white rat. Unpublished Ph.D. thesis, State Univer. of Iowa, 1947.
13. Wilkinson, B. A statistical consideration in psychological research. *Psychol. Bull.*, 1951, **48**, 156–158.
14. Winnick, W. The discriminative function of drive-stimuli independent of the action of the drive as motivation. *Amer. J. Psychol.*, 1950, **63**, 196–205.

Journal of Experimental Psychology
Vol. 45, No. 6, 1953

EYELID CONDITIONING AS A FUNCTION OF THE CS-US INTERVAL[1]

WALLACE R. McALLISTER

State University of Iowa

The length of the time interval between the onsets of the conditioned stimulus (CS) and the unconditioned stimulus (US) has long been considered one of the important variables determining the frequency of conditioned responses (CR's) and has been studied in a number of experiments. Of those employing the delayed-conditioning procedure (**6, 7, 9**), all but one (**6**) have used a visual CS.[2] On the other hand, investigators using the trace procedure (**1, 10, 13, 14**) have all utilized a brief, auditory CS. With the exception of three (**6, 13, 14**), all of these experiments involved eyelid conditioning.

The optimal interval was found to be around 400 to 500 msec. in all but three of the above studies. In the exceptions (**1, 6, 14**), the optimal intervals lay at 300, 666, and 200 msec., respectively. However, only the first of these involved the eyelid response. Thus it is apparent that the results have been quite consistent, at least for eyelid conditioning. Nevertheless, in the studies involving eyelid conditioning, a different CS was used for each of the two conditioning techniques. Thus, it is not known whether the relationship between conditioning and the interstimulus interval is the same for different types of CS's (i.e., for stimulation of different sensory modalities) when the same conditioning technique is used.

The purpose of this experiment was to study the relationship between the conditioning of the eyelid response and the length of the time interval between the onset of the CS (tone) and the US (puff of air) using the delayed-conditioning technique.

METHOD

Subjects and design.—The *S*s were 105 members of an introductory course in psychology at the State University of Iowa. Each *S* was assigned at random to one of five groups, each group being conditioned with one of the following CS–US intervals: 100, 250, 450, 700, and 2500 msec. Forty-five *S*s were assigned to the 450-msec. group and 15 to each of the others.[3] For all conditions the proportion of women to men was fixed at a ratio of eight to seven. Subsequent to the main experiment, 30 additional *S*s were run, 15 under the 250-msec. condition and 15 under the 450-msec. condition. The reason for running them will be discussed later.

Apparatus.—The CS was a tone of 1000 cycles, 50 db above each *S*'s threshold,[4] generated

[1] This article is based on a portion of a dissertation submitted to the Graduate College of the State University of Iowa in partial fulfillment of the requirements for the Ph.D. degree. The writer wishes to express his appreciation to Professor Kenneth W. Spence for valuable aid and advice offered throughout the course of the experiment. The writer is also indebted to Mr. John P. Dolch for technical assistance.

[2] *Delayed conditioning* here refers to the technique in which some time greater than zero intervenes between the onset of the CS and the onset of the US and in which the CS overlaps (some portion of) the US. *Trace conditioning* here refers to the technique in which the offset of the CS occurs before the onset of the US at a time interval greater than zero. This use of terms is somewhat at variance with others' terminology. (Cf. **2**, p. 575.)

[3] The *S*s in the 450-msec. group were subdivided into three groups of 15 *S*s each at the end of the conditioning trials and were then given differential treatment. The results obtained will be published elsewhere (**8**).

[4] The auditory threshold of each *S* was roughly determined before the conditioning trials by presenting one descending and one ascending series of a continuously sounding, 1000-cycle tone (method of limits). The *S* was instructed to

by a Hewlitt-Packard audio oscillator, Model 200D, and delivered to *S* through a set of Permoflux headphones, P.D.R.-8.

The US was a puff of air, of approximately 1.6 lb./sq. in., produced by the fall of a column of mercury through a distance of 80 mm., and delivered to the right cornea. The onsets and durations of the CS and the US were controlled by two Hunter-Brown decade-type electronic interval timers (5). After its onset, the US continued for 400 msec., and the CS was extended to overlap it so that both stimuli terminated simultaneously. The onset and offset of the stimuli were recorded on a polygraph by means of a signal marker.

The eyelid movement was recorded by a combination of electrical and mechanical means which has been described elsewhere (11). Briefly, the method of recording involved (*a*) a small plastic lever fastened to the eyelid with adhesive tape, (*b*) a light-weight microtorque potentiometer, the variable (rotating) arm of which was connected to the plastic lever by a silk thread, (*c*) a fixed-frequency oscillator, (*d*) an audio-frequency amplifier, (*e*) a full-wave rectifier for rectifying the amplified signal, (*f*) a Brush BL 902 pen recorder, and (*g*) a polygraph.

The *S*s were seated in an adjustable dental chair which was in a semisoundproof room adjoining that in which the recording apparatus and stimulus controls were located. The room was under a constant illumination of .15 ft.-candles.

Conditioning procedure.—After *S* was seated comfortably in the chair, instructions designed to induce a neutral set were read to him, and any questions about the procedure were answered. Prior to the conditioning trials, three presentations of the CS alone were given to insure that *S* was following instructions and to determine whether *S*'s eyelid response was already conditioned to the stimulus. If *S* gave three CR's to the tone, he was eliminated. Two *S*s were discarded for this reason.

At random intervals of 2, 3, or 4 sec. before the CS was presented, a weak buzzer was sounded to serve as a ready signal. At this signal *S* was instructed to fixate a lighted disk (.19 apparent ft.-candles) located about 92 in. from his eye and approximately 4.5 in. above eye level. Upon fixating the light, *S* was instructed to blink once. The trial was then given. The intertrial interval averaged 20 sec., varying in a fixed, irregular order of 15, 20, or 25 sec. One hundred conditioning trials were given to each *S* during one experimental session.

Measurement of the CR.—In defining and counting CR's, certain problems arise. In the first place, as interstimulus intervals become shorter, there is less opportunity for a response to anticipate the onset of the US. Therefore, if only anticipatory responses were counted as CR's, poorer performance might be found for shorter interstimulus interval groups merely because of this restriction in measurement. In order to lessen this possibility, test trials, in which no US was presented, were used on 20% of the trials for each group, and on the test trials the time interval in which CR's were counted was lengthened. For each *S* one-third of the test trials occurred on the trial prior to each successive fifth trial, one-third on each successive fifth trial, and one-third on the trial following each successive fifth trial. The order was counterbalanced within each group. This procedure was adopted to prevent *S*s from determining which trial would be unreinforced and to keep the average ordinal number of each test trial a multiple of five.

For most groups it was also possible to count anticipatory CR's. Thus two measures of a CR were obtained—one in terms of anticipatory responses and one in terms of responses made in a longer interval on the test trials. For each group the longer interval extended 200 msec. beyond the usual point of onset of the US. This value was selected arbitrarily. The time intervals in which a movement of the penwriter 1 mm. or more was counted as a CR are given in Table 1. In recording the anticipatory CR data, responses on the test trials were counted only if the response fell within the latencies designated for anticipatory CR's.

The fact that the eye often makes an unconditioned blink (an original response) to the onset of a tone constitutes a second problem. Since these original responses occur with a very short

TABLE 1

INTERVALS (IN MILLISECONDS) IN WHICH RESPONSES WERE COUNTED AS CR'S

CS–US Intervals	Intervals Used for Anticipatory Responses	Intervals Used for Test Trial Responses
100	—	100–300
250	100–250	100–450
450	100–450	100–650
700	100–700	100–900
2500	100–2500	100–2700

lower his finger when he no longer heard the tone (descending series) and to raise his finger as soon as he heard the tone (ascending series). The attenuation of the tone when *S* thus responded was noted for both series, the mean attenuation being taken as the threshold. The tone (CS) was set 50 db above this value for the conditioning trials.

latency, it was decided to count no response which occurred within the first 100 msec. as a CR and in this manner to avoid introducing original responses into the data. Thus it was impossible to count anticipatory CR's for the 100-msec. group.

A further problem lies in the fact that the eye blinks randomly. This means that the longer CS–US intervals will include a greater number of such random blinks than the shorter intervals and will artificially increase the number of CR's counted for those groups. In an attempt to solve this problem, the percentage of CR's occurring on the first block of trials was subtracted from the percentage of CR's occurring on each subsequent block of trials.

Results

Acquisition of CR.—Performance curves showing the percentage of CR's made on the test trials plotted against blocks of two test trials are given in Fig. 1. The fact that the percentage

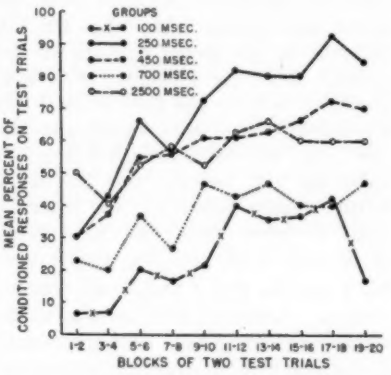

Fig. 1. Mean percentage of CR's in successive blocks of two test trials for each group

of CR's on the first block of trials tends to be larger the longer the CS–US interval is to be expected because the longer CS–US intervals permit more random blinks to occur. To take this factor into account, the correction for random blinking mentioned above (which amounts to using each *S* as his own control) was made. The curves, after this correction was carried out, are shown in Fig. 2. It is apparent that each curve grows systematically, with the 250-msec. group showing the greatest increase in performance. The increases were smaller for groups run with shorter or with longer CS–US intervals. The sharp drop in the curve at the last point of the 100-msec. group is probably a chance occurrence only. Since the results obtained with the anticipatory CR measure were so similar to these results, those data are not presented in this paper.[5]

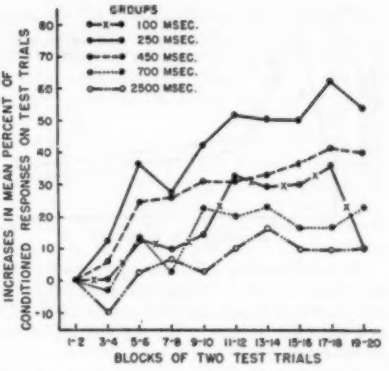

Fig. 2. Increases in mean percentage of CR's in blocks of two test trials for each group

At the completion of the experiment it was discovered that through random sampling a greater proportion of *S*s scoring high on a scale of manifest anxiety had been included in the 250-msec. group. Since it has been shown that such *S*s condition better than other *S*s (**11, 12**), the high level of

[5] A two-page table giving anticipatory CR data of the main and of the follow-up experiment and the test-trial data of the latter study has been deposited with the American Documentation Institute. Order Document No. 3919 from American Documentation Institute, Auxiliary Publications project, Photoduplication Service, c/o Library of Congress, Washington 25, D. C., remitting $1.25 for microfilm (images 1 inch high on standard 35 mm. motion picture film) or $1.25 for photoprint readable without optical aid.

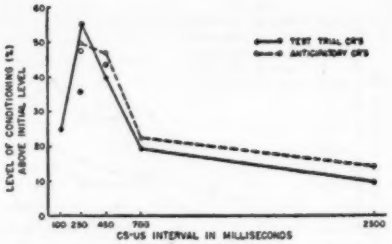
LEVEL OF CONDITIONING (%) ABOVE INITIAL LEVEL
TEST TRIAL CR'S
ANTICIPATORY CR'S
100 250 450 700 2500
CS-US INTERVAL IN MILLISECONDS

FIG. 3. Level of conditioning (%) above the initial level of conditioning as a function of the time interval separating the onsets of the CS and the US. (See text for explanation of unjoined circles.)

performance reached by the 250-msec. group might be accounted for by that fact. To check on this possibility, 30 additional Ss, all scoring in the middle range of the anxiety scale, were run, 15 under each of the 250- and 450-msec. conditions. The final level reached by these two groups was similar but the 250-msec. group conditioned much more rapidly.

Conditioning level as a function of time interval.—To examine the effect of the CS–US interval upon the final level of conditioning reached, the mean percentage of increases (i.e., the percentage of CR's remaining after the correction for random blinking) in anticipatory CR's for the last 30 trials and in test trial CR's for the last 6 test trials was computed for each group. In Fig. 3 these percentages are plotted against CS–US intervals. Inspection of the figure reveals that the 250-msec. group reached a higher level of conditioning than did any other group. The longer the interval beyond the 250-msec., the poorer was the performance; the one shorter interval was also inferior.

The same computations were made on the data obtained in the follow-up study. In Fig. 3 the results obtained are plotted as unjoined circles; the open circles represent anticipatory CR's, the closed circles, test-trial CR's. Again the 250-msec. group was found superior to the 450-msec. group with respect to the anticipatory CR's, although the difference was not as great as in the original experiment. In terms of the test-trial data, the 450-msec. group was superior. However, more weight should be given the anticipatory CR data for two reasons: (*a*) the data are based on 30 measures instead of 6 and thus are probably more reliable; and (*b*) the 30 trials from which the anticipatory CR data were obtained include the 6 test trials.

In order to evaluate the differences between the final levels of conditioning and to check on possible sex differences, a factorial analysis of variance was carried out on the data from the main experiment with the CS–US interval as one factor and sex as the other.[6] For the anticipatory CR's, the differences in the final level of the corrected scores were significant beyond the .1% level for CS–US intervals; for sex, beyond the 1% level (with women superior); for interaction, at more than the 50% level (F = 7.02, 4.79, and .05, with 3 and 82, 1 and 82, and 3 and 82 *df*, respectively). A similar analysis was made on the test-trial data. The differences in the final level of the corrected scores were found to be significant between the 1% and 5% levels for the interval factor; for sex, between the 20% and 30% levels (with women superior); for interaction, at more than the 50%

[6] Before these analyses were made, the assumption of homogeneity of population variances was checked by computing Bartlett's test. In no case were the chi-square values significant at the 5% level. The assumption of normality of the population distribution was assumed to be tenable from inspection of the data.

level (F = 2.91, 1.32, and .90, with 4 and 95, 1 and 95, and 4 and 95 *df*, respectively).

Since the superiority of the 250-msec. group over the 450-msec. group was contrary to previous findings, it was of interest to determine whether the difference was statistically significant. Therefore, t tests (using the within-cells variance estimates from the above analyses) were computed between the increases in anticipatory CR's and between the increases in test-trial CR's for the 250- and 450-msec. groups. For the anticipatory-CR data t was .32, and for the test-trial CR data t was 1.35. Thus, the differences between the 250- and 450-msec. groups were not reliable.

A similar analysis (with CS–US interval and sex as factors) was carried out with the data collected in the follow-up study. The F ratios obtained were all less than unity regardless of whether the anticipatory-CR data or the test-trial CR data were used. Thus, the differences between the 250- and 450-msec. groups again were not statistically significant. Although not significant, the sex difference was in favor of the men.

Discussion

Effects of CS–US interval.—Several comments should be made concerning the values plotted in Fig. 3. In the first place, the value plotted for the 100-msec. group is probably low because of the sharp drop obtained, for no known reason, on the last two test trials. Secondly, it seems unusual that the level of conditioning should be so much lower in the 700-msec. group than that usually obtained with a visual CS. It is possible that the low level is due to random sampling. In the third place, two compensating artifacts affect the value plotted in Fig. 3 for the 2500-msec. group. Myers (9) found that the number of eyelid responses increased (14% in 80 trials) as a function of the number of times the eye was puffed without being paired with a neutral stimulus. Thus, the slight increase in performance found for the 2500-msec. group in this study might be attributed, in part at least, to that fact. Offsetting such a possibility, however, is another circumstance. Only one CR was counted per trial no matter how many blinks occurred, and to correct for random blinks the percentage of responses on the first block of ten trials was subtracted from every subsequent block. Thus, if *Ss* began to condition, there would be less opportunity for an increase in conditioning to be demonstrated for that interval because of the correction. The performance curve would in this way be artificially lowered. It is difficult to determine to what extent these two factors offset one another. However, on the basis of these data and those of Myers,[7] it appears safe to conclude that eyelid conditioning under as long an interval as 2500 msec. is poor or negligible.

The results of the present experiment are in agreement with those of previous studies in showing that the level of conditioning varies with the time interval between the onsets of the CS and the US. They differ from most earlier studies in suggesting that intervals as short as 250 msec. may result in superior performance. It will be recalled that in the majority of previous studies maximum conditioning was found in the neighborhood of 400–500 msec. Many of these studies, however, employed a visual CS, and when an auditory CS was used, the conditioning was of the trace variety. The results of this study suggest that the optimal CS–US interval may be shorter than hitherto supposed (e.g., **3, 4**), at least when an auditory stimulus is used as a CS under the delayed-conditioning procedure.

Effects of sex.—Although a significant sex difference in favor of women was found with one of the two measures in the major experiment, in the follow-up study the difference was in the opposite direction but was not significant. The over-all results, therefore, do not support the conclusion that there is a true sex difference in conditioning.

[7] Using an increase in brightness as the CS, a blow from an electromagnetic hammer to the corner of the eye as the US, and running *Ss* under 500-, 1000-, 1500-, and 2500-msec. interstimulus intervals, Myers (9) found that the final level of conditioning (corrected for random blinking) decreased monotonically beyond the 500-msec. interval. The curve started approximately at 33% CR's for the 500-msec. interval and decreased to about 5% for the 2500-msec. interval. To correct for an increase in CR's attributable merely to stimulation by the US, he subtracted the increase in CR's found in a control group to which only the US was administered.

Summary

The eyelid response of five groups of *Ss* was conditioned, by the delayed-conditioning technique, with CS–US intervals of 100, 250, 450, 700, and 2500 msec., respectively. A 1000-cycle tone, set 50 db above each *S*'s threshold, was the CS; a fall of mercury in a manometer through a distance of 80 mm., the US. Twenty of the 100 trials were nonreinforced; i.e., were test trials. Two measures were obtained, anticipatory CR's and CR's counted in a longer interval on the test trials.

Subsequent to the main experiment 30 additional *Ss* were run, 15 under the 250- and 15 under the 450-msec. condition. This second study was conducted when it was found that through random sampling a disproportionate number of *Ss* scoring high on a test of manifest anxiety had been included in the 250-msec. group. A check on possible sex differences was also made when the data were analyzed. The main findings are listed below.

1. The level of conditioning was found to vary with the time interval between the onsets of the CS and the US. The optimal interval was found to be 250-msec. although the difference between the 250- and 450-msec. groups was not significant.

2. Conditioning with intervals as long as 2500 msec. was markedly inferior, possibly negligible.

3. Little evidence for sex differences in conditioning was found.

(Received October 15, 1952)

References

1. Bernstein, A. L. Temporal factors in the formation of conditioned eyelid reactions in human subjects. *J. gen. Psychol.*, 1934, **10**, 173–197.
2. Brogden, W. J. Animal studies of learning. In S. S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley, 1951.
3. Hull, C. L. *Principles of behavior*. New York: D. Appleton-Century, 1943.
4. Hull, C. L. *Essentials of behavior*. New Haven: Yale Univer. Press, 1951.
5. Hunter, T. A., & Brown, J. S. A decade-type electronic interval-timer. *Amer. J. Psychol.*, 1949, **62**, 570–575.
6. Kappauf, W. E., & Schlosberg, H. Conditioned responses in the white rat: III. Conditioning as a function of the length of the period of delay. *J. genet. Psychol.*, 1937, **50**, 27–45.
7. Kimble, G. A. Classical conditioning as a function of the time between conditioned and unconditioned stimuli. *J. exp. Psychol.*, 1947, **37**, 1–16.
8. McAllister, W. R. The effect on eyelid conditioning of shifting the CS–US interval. *J. exp. Psychol.*, 1953, **45**, 423–428.
9. Myers, J. A. An experimental investigation of the effect of varying the time between the onsets of the conditioned and unconditioned stimuli on the conditioned eyelid response. Unpublished doctor's dissertation, Univer. of Iowa, 1950.
10. Reynolds, B. The acquisition of a trace conditioned response as a function of the magnitude of the stimulus trace. *J. exp. Psychol.*, 1945, **35**, 15–30.
11. Spence, K. W., & Taylor, J. A. Anxiety and strength of the UCS as determiners of the amount of eyelid conditioning. *J. exp. Psychol.*, 1951, **42**, 183–188.
12. Taylor, J. A. The relationship of anxiety to the conditioned eyelid response. *J. exp. Psychol.*, 1951, **41**, 81–92.
13. Wolfle, H. M. Time factors in conditioning finger-withdrawal. *J. gen. Psychol.*, 1930, **4**, 372–379.
14. Wolfle, H. M. Conditioning as a function of the interval between the conditioned and the original stimulus. *J. gen. Psychol.*, 1932, **7**, 80–103.

Journal of Experimental Psychology
Vol. 45, No. 6, 1953

THE EFFECT ON EYELID CONDITIONING OF SHIFTING THE CS-US INTERVAL[1]

WALLACE R. McALLISTER

State University of Iowa

Although the time interval between the onsets of the conditioned stimulus (CS) and the unconditioned stimulus (US) has long been considered one of the important variables determining the level of conditioning, little experimentation has been conducted on the effect of shifting the interval after a high level of performance has been reached under an optimal interval.

Three experimenters have conducted experiments relative to this problem. Pavlov (**4**) and Rodnick (**5**), working with the salivary and GSR responses, respectively, lengthened the CS–US interval by several seconds. Pavlov reported that when the shift from a short to a long interval was made in one step, the conditioned response (CR) first disappeared, then reappeared immediately preceding the US, and finally shortened in latency. On the other hand, Rodnick found that the latency of the CR lengthened steadily with the trials subsequent to the shift. The third experimenter, Nagaty (**3**), utilized an instrumental, rather than a classical, conditioning procedure. After the instrumental response was well established, he found that it decreased in vigor and frequency when the sequence of presentation of the CS and of the US was reversed (i.e., when changed to a backward conditioning procedure).

Thus there is no experimental evidence pertaining directly to the effects on eyelid conditioning of shifting the CS–US interval from an optimal one to one known not to be conducive to conditioning. The purpose of this experiment was to obtain information concerning the effects of such a shift on the frequency of the conditioned eyelid response.

METHOD

Subjects and design.—Sixty members of an introductory course in psychology at the State University of Iowa were used as *S*s, 15 (8 women and 7 men) in each of four groups. All groups were given 100 conditioning trials on Day 1 with a 450-msec. CS–US interval, under exactly the same conditions and then were given differential treatment. Group A was brought back the following day (Day 2) and was administered 100 additional trials with a 2500-msec. interstimulus interval. Group B was given 100 additional trials on Day 2 with a 35-msec. CS–US interval. Group C was given 40 extinction trials (i.e., presentation of the CS alone) on Day 2. Group D was administered 10 extinction trials (or trials to a criterion of three consecutive trials with no CR) immediately after the first 100 trials on Day 1.

All *S*s were selected at random from the class as a whole except for those in Group C. The *S*s in that group were selected at random from students in the course scoring in the middle range on a scale of manifest anxiety and were run subsequent to the other groups to check for possible reminiscence and/or "warm-up" effects. The selection procedure was adopted for reasons discussed elsewhere (**1**) which do not pertain to this study. Since the performance of all groups on the conditioning trials was comparable (see below), this method of selection can be disregarded in the interpretation of the results.

Apparatus.—The CS was a tone of 1000 cycles, 50 db above each *S*'s threshold, generated

[1] This article is based on a portion of a dissertation submitted to the Graduate College of the State University of Iowa in partial fulfillment of the requirements for the Ph.D. degree. The writer wishes to express his appreciation to Professor Kenneth W. Spence for valuable aid and advice offered throughout the course of the experiment. The writer is also indebted to Mr. John P. Dolch for technical assistance. The results of this experiment were presented at the 1953 meeting of the Midwestern Psychological Association.

by a Hewlitt-Packard audio oscillator, Model 200D, and delivered through a set of Permoflux headphones, P.D.R.-8.[2]

A puff of air, of about 1.6 lb./sq. in., produced by the fall of a column of mercury through a distance of 80 mm., delivered to the right cornea, constituted the US. The US continued for 400 msec. after its onset, and the CS was extended to overlap it so that both went off simultaneously. The onset and offset of the stimuli were recorded by means of a signal marker on a polygraph. The eyelid movement was recorded by a combination of electrical and mechanical means (7).

The *Ss* were seated in an adjustable dental chair located in a semisoundproof room adjoining that in which the recording apparatus and stimulus controls were located. The room was under a constant illumination of .15 ft.-candles.

Procedure.—Before beginning training, the CS was presented three times alone to insure that *S* was following instructions and to determine whether the eyelid response was already conditioned to the stimulus. If *S* gave three CR's to the tone, he was eliminated. Two *Ss* were discarded for this reason.

A weak buzzer was used as a ready signal and was presented at random intervals of 2, 3, or 4 sec. before the trial. Upon hearing the ready signal, *S* was instructed to fixate a lighted disk and to blink once. The disk, located 92 in. in front of *S* and about 4.5 in. above eye level, had a constant brightness of .19 apparent ft.-candles. The intertrial interval averaged 20 sec., varying in a fixed irregular order of 15, 20, or 25 sec.

Measurement of CR.—In order to be able to count CR's for the *Ss* shifted from an interstimulus interval of 450 msec. to one of 35 msec. a partial reinforcement regimen was adopted for all groups; i.e., test trials were used. Only the responses on those trials were counted for the 35 msec. group. Thus, for all groups on the first day the US was not presented on 20 of the 100 trials. For each group the nonreinforced trials occurred, on the average, on each fifth trial. The same procedure was maintained on the second day for the two groups with the shifted CS–US interval.

To avoid counting as CR's the unconditioned blinks (original responses) to the onset of the tone, it was decided not to count any response occurring within the first 100 msec. after the onset of the CS. Thus, any movement of the penwriter 1 mm. or more in amplitude was considered to be a CR if it occurred within the interval from 100 to 450 msec. after the onset of the CS. In the case of *Ss* shifted to the 2500-msec. interval, the CR's were also counted in the interval from 100 to 2500 msec. so that in case the CR's lengthened in latency to a point beyond the range of the shorter interval, they would still be recorded.

On several occasions *Ss* closed their eyes before 100 msec. and kept them closed until after the period in which CR's were counted. When that occurred, the percentage of CR's for the block of trials was computed by disregarding that trial.

[2] For a more detailed description of the apparatus and procedure see (1).

Results

In Table 1 are given the mean percentages of CR's for each group for each block of 10 trials and for each block of 2 test trials of the first 100 trials. Since a comparison of the performance of Groups A, C, and D after the 100 trials was to be made in terms of blocks of 10 trials, a simple analysis of variance was computed for the mean percentage of CR's on the last three blocks of 10 trials to check the comparability of the groups at that stage of training. For an analogous reason a similar analysis was computed with the mean percentage of CR's on the last three blocks of test trials for Groups B, C, and D. The *F* ratios for both analyses were less than one; therefore, the null hypothesis was tenable in each case. The groups included in each analysis could thus be considered to be comparable at the end of the first 100 trials.

In Fig. 1 the mean percentage of CR's is plotted against successive blocks of 10 trials for the *Ss* who were run under the 450-msec. interstimulus interval on Day 1 and who were shifted to the 2500-msec. interval on Day 2. Two curves are drawn for the second day's performance. The solid line represents the percentage of CR's made in the interval from 100-450 msec. after the onset of the CS, i.e., the same criterion as that used on the first day. The dashed curve joining the solid circles represents the percentage of CR's made during the 100–2500-msec. interval after the on-

TABLE 1

MEAN PERCENTAGE OF CR's FOR ALL TRIALS AND FOR TEST TRIALS ON FIRST 100 TRIALS

All Trials					Test Trials				
Blocks 10 Trials	Group A	Group B	Group C	Group D	Blocks 2 Trials	Group A	Group B	Group C	Group D
1	16.7	12.5	14.2	7.4	1	30.0	10.0	16.7	10.0
2	30.1	22.1	21.3	25.8	2	43.3	20.0	26.7	23.3
3	35.3	26.2	30.7	42.7	3	46.7	43.3	26.7	50.0
4	41.3	39.1	43.3	45.4	4	50.0	43.3	36.7	53.3
5	40.0	44.7	41.4	48.0	5	63.3	40.0	56.7	46.7
6	48.4	47.3	45.3	46.4	6	60.0	56.7	46.7	53.3
7	57.3	51.8	46.2	55.5	7	66.7	46.7	50.0	56.7
8	56.9	51.2	52.5	64.7	8	66.7	56.7	60.0	56.7
9	61.3	52.5	55.9	63.1	9	66.7	60.0	60.0	70.0
10	62.7	53.8	63.9	65.9	10	66.7	56.7	80.0	66.7
Mean % last 3 blocks	60.3	52.5	57.4	64.6	Mean % last 3 blocks	66.7	57.8	66.7	64.5

set of the CS, i.e., any anticipatory CR. Also plotted for purposes of comparison are the extinction-trial data for Groups C and D.

It is apparent that the shift of the CS–US interval resulted in a gradual, continuous decrease in the percentage of CR's regardless of the interval in which the CR's were counted. The final level of the dashed curve for Group A is approximately the same as the initial level of a group condi-

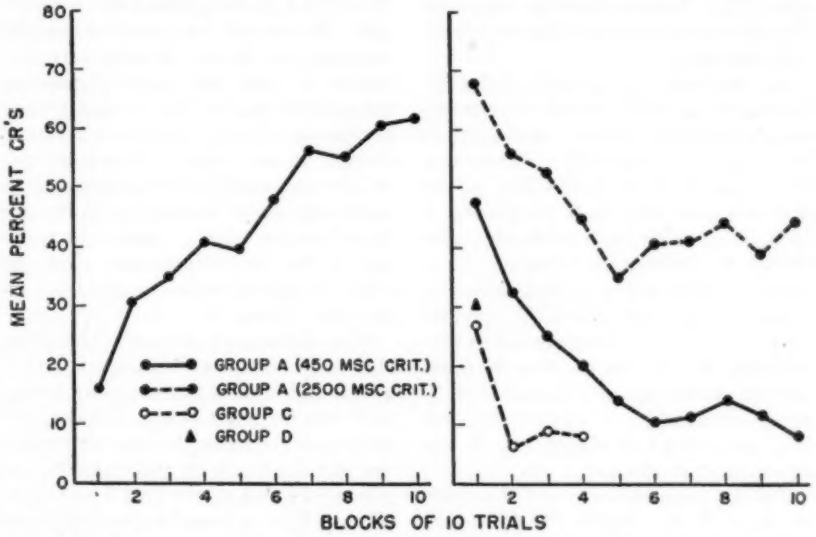

FIG. 1. The mean percentage of CR's per block of ten trials for Group A under the 450-msec. and under the 2500-msec. CS–US intervals. Plotted also are the mean percentages of CR's on the extinction trials for Groups C and D.

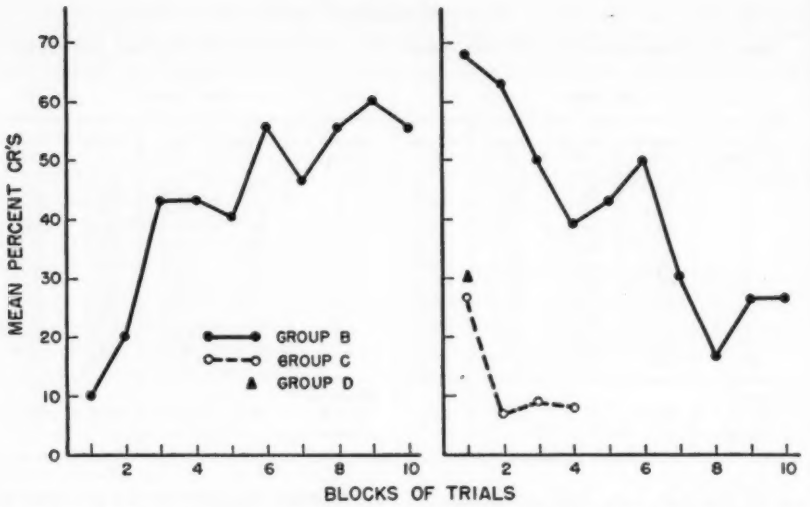

FIG. 2. The mean percentage of CR's per block of trials for Group B under the 450-msec. and under the 35-msec. CS–US intervals. Plotted also are the mean percentages of CR's for Groups C and D on their extinction trials. For Group B the points on the abscissa represent blocks of two test trials; for Groups C and D, blocks of ten trials.

tioned only under the 2500-msec. interval (1). In that case the high level of performance was attributed to random blinking.

An evaluation was made of the difference between the postshift performances of Groups A and C and A and D by means of *U* tests (2). Comparing the mean percentage of CR's on the first ten postshift trials for Group A (450-msec. criterion) with that for Group D (450-msec. criterion), a *z* value of 1.60 was obtained which is significant at only the 11% level of confidence. Comparing the mean percentages of CR's on the first 40 postshift trials for Groups A and C (450-msec. criterion), a *z* value of 2.1 was obtained, which is significant at the 3% level of confidence.

The mean percentages of CR's made by those *S*s run under the 450-msec. interval on the first day who were shifted to a 35-msec. interval on the second day (Group B) are presented in Fig. 2. The extinction data of Groups C and D are also plotted for comparison. It should be noted that the abscissa for Group B is in terms of blocks of two test trials (occurring every fifth trial on the average) while for Groups C and D it is in terms of blocks of ten trials. However, the points are roughly comparable since each represents average performance based on ten trials. Again the gradual decline in performance after the shift of interstimulus interval is evident for Group B.

The differences between the postshift performances of Groups B and C and B and D were evaluated by means of *U* tests. For Groups B and C the difference between the mean percentage of CR's made on the first 40 trials (Group C) and on the first 8 test trials (Group B) was found to be significant beyond the 1% level ($z = 3.30$). The difference in the mean percentage of CR's made on the first 10 trials

(Group D) and on the first 2 test trials (Group B) was found to be significant beyond the 1% level ($z = 2.93$).

Taking both analyses into account, these results provide strong evidence that the performance for the groups shifted to nonoptimal CS–US intervals was superior, for a number of trials, in comparison with groups extinguished in the usual manner.

Finally, the performance of Groups C and D was very similar on the first ten extinction trials (27% and 30% CR's, respectively). Thus neither reminiscence nor "warm-up" are indicated as factors in this experiment.

Discussion

The fact that the performance curves for both groups shifted from an optimal to a nonoptimal CS–US interval decrease gradually from a high level implies, so far as a reinforcement theory is concerned, that the conditions of reinforcement were changed to such an extent as to lead to extinction, i.e., that there was little or no reinforcement of the CR. In the case of *Ss* shifted to the shorter (35-msec.) interval, the unconditioned response occurred considerably before the CR and presumably the reinforcement did also. On the basis of this reasoning, a reinforcement theory would have to assume that the occurrence of the reinforcing state of affairs prior to a response is not an effective condition for the strengthening of a response.

The extinction of the CR in the case of the group in which the CS–US interval was increased from 450 msec. to 2500 msec. also implies that the reinforcing conditions were not adequate for the maintenance of the learned response. In this instance, delaying the reinforcement approximately 2 sec. was sufficient to lead to its extinction.

The question remains as to why the level of performance of the groups shifted to nonoptimal interstimulus intervals was higher than that of the groups extinguished by presentation of the CS alone. Probably this difference in performance is the result of a difference in drive. The groups which were shifted to nonoptimal intervals had their drive maintained (the US was administered on 80% of the trials) while reinforcement was ineffective. The groups extinguished in the usual manner had neither reinforcement nor drive maintained. Since response strength is presumed to be a function of drive, among other variables (**6**, p. 252), the differences in extinction of these groups would be expected.[3]

Summary

Four groups of 15 *Ss* each were given 100 conditioning trials with a 450-msec. CS–US interval and then were given differential treatment. Group A was administered 100 additional trials the following day with a 2500-msec. interstimulus interval; Group B, with a 35-msec. interstimulus interval. Group C was given 40 extinction trials (CS presented alone) on the next day; Group D, 10 extinction trials (or trials to a criterion of three consecutive trials with no CR) immediately after the conditioning trials.

The percentage of CR's for the groups shifted to nonoptimal CS–US intervals decreased gradually and steadily while for the groups extinguished in the usual manner the percentage of CR's dropped sharply. Although the decrease in performance

[3] This interpretation of results is similar to that made by Nagaty (**3**). He concluded that the reason his *Ss* maintained an instrumental response better when run under backward conditioning intervals (shock presented before buzzer) than a control group presented with the buzzer alone was due to the shock which maintained drive (fear) at a higher level.

of the groups shifted was interpreted as the result of extinction, their superior performance in comparison with the groups extinguished in the normal manner was attributed to the maintenance of drive through the continued presentation of the US.

(Received October 15, 1952)

References

1. McAllister, W. R. Eyelid conditioning as a function of the CS–US interval. *J. exp. Psychol.*, 1953, **45**, 417–422.
2. Mann, H. B., & Whitney, D. R. On a test of whether one of two random variables is stochastically larger than the other. *Ann. math. Statist.*, 1947, **18**, 50–60.
3. Nagaty, M. O. The effect of reinforcement on closely following S–R connections: I. The effect of a backward conditioning procedure on the extinction of conditioned avoidance. *J. exp. Psychol.*, 1951, **42**, 239–246.
4. Pavlov, I. P. *Conditioned reflexes.* (Translated by G. V. Anrep.) London: Oxford Univer. Press, 1927.
5. Rodnick, E. Characteristics of delayed and trace conditioned responses. *J. exp. Psychol.*, 1937, **20**, 409–425.
6. Spence, K. W. Theoretical interpretations of learning. In C. P. Stone (Ed.), *Comparative psychology.* (3rd Ed.) New York: Prentice-Hall, 1951.
7. Spence, K. W., & Taylor, J. A. Anxiety and strength of the UCS as determiners of the amount of eyelid conditioning. *J. exp. Psychol.*, 1951, **42**, 183–188.

Journal of Experimental Psychology
Vol. 45, No. 6, 1953

THE PAINTAL INDEX AS AN INDICATOR OF SKIN-RESISTANCE CHANGES TO EMOTIONAL STIMULI

DONALD N. ELLIOTT
Wayne University

AND EUGENE G. SINGER
University of Detroit

In an article in this journal, Paintal (2) described a new method of evaluation of individual galvanic skin responses (GSR) which eliminated difficult formulae and conversions of the raw data into arbitrary derived measures. The method also appeared to eliminate the necessity of considering the basic skin resistance (BSR) in evaluating a GSR. This, of course, would simplify the problem greatly, since the BSR is an important factor in the size of the GSR, a positive relationship of substantial size existing (1, 3).

Briefly, Paintal's method consisted of eliciting a "maximum" GSR (MGSR) by means of a faradic shock, and evaluating other GSR's in terms of this maximum $\left(\frac{\text{GSR}}{\text{MGSR}} \times 100\right)$. His data on 450 psychotics and 450 normals indicated that this percentage bore no relationship to *S*'s BSR, and would therefore be a more useful index in evaluating the significance of GSR's than their absolute size.

The study reported here is a brief investigation of the use of the Paintal Index in a different type of experimental situation than that used by Paintal, since tentative preliminary findings appeared to indicate that the Index might possibly be related to the BSR in the experimental situation described below.

Method

Subjects.—The *S*s were 32 undergraduate students, 10 female and 22 male. The median age of the *S*s was 21; range, 17 to 31 yr.

Apparatus.—The instrument used to measure the skin resistance was the Lafayette Instrument Company's Psycho-galvanic Response Unit. A change in electrodes was made, substituting a pair of brass plates for palmar attachment for the regular finger electrodes which were found to give abnormally high resistance readings. Use of the palmar electrodes with Redux electrode paste gave basic skin-resistance readings within the expected range.

Procedure.—The stimuli used to elicit GSR's consisted of five emotionally loaded words (love, sex, body, kiss, and push) and an unexpected loud noise produced by slapping a 3 × 5-in. piece of wood against a table top. This noise had been found to elicit a maximum and consistent GSR. Five unloaded words (chair, white, large, dog, and bread) were interspersed with the loaded words as an aid to re-establishment of normal skin resistance.

Each *S* was tested three times, with three-week intervals between each trial. At each trial *S* was told to respond as quickly as possible with a word association to each word. The words were varied in random fashion from trial to trial. The loud noise was presented without warning and at a different time in each trial. The *S*s were blindfolded, and sufficient time was given at the start of each trial (5–10 min.) and between each emotional stimulus to allow for a stable determination of the BSR.

Three measurements were recorded for each *S*: (*a*) his BSR, which was the mean resistance in ohms before the presentation of each loaded word and the loud sound; (*b*) his GSR, which was the mean change in resistance to the five emotionally loaded words; and (*c*) his MGSR, which was the change in resistance to the loud sound. These three measurements were recorded at each of the three trials.

Results and Discussion

Listed in Table 1 are the correlations between the BSR and GSR, MGSR, and the Paintal Index. Contrary to our tentative preliminary findings, we found no relationship between the Paintal Index and BSR

TABLE 1

CORRELATIONS BETWEEN BSR AND GSR, MGSR, AND THE PAINTAL INDEX

Correlation between BSR and		
GSR	MGSR	Paintal Index
.412	.401	.061

(r = .06); this is in agreement with the results reported by Paintal. It will also be noted from the correlations that regardless of the extent of the emotional impact of a stimulus, the change in skin resistance is determined to an appreciable, and approximately equal, degree by *S*'s BSR.

The value of the Paintal Index is seen, consequently, to lie in the fact that it (*a*) is unaffected by the *S*'s BSR, and (*b*) enables one to interpret the extent of the emotional impact of a stimulus in terms of a possible maximum reaction. The mean Index size for our *S*s was 51, indicating GSR's to the loaded words of approximately half the possible maximum.

One of the greatest difficulties associated with the use of the GSR as an indicator of emotion has been the fact that, regardless of the particular unit of measurement utilized, any absolute measure of change in skin resistance had meaning only when compared with other changes in the *same S*. Inter-*S* comparisons have always been questionable because of the fact of large individual differences in the size of the BSR and GSR. The Paintal Index, however, does not appear to reflect such individual differences, and since it is easily interpretable as a percentage of a possible maximum response, it should make inter-*S* as well as intra-*S* comparisons more meaningful than the use of absolute measures of skin-resistance change.

SUMMARY

The supposed independence of the Paintal Index (**2**) and basic skin resistance was confirmed in a study involving GSR's to emotionally toned words as compared with maximum GSR's to a loud noise.

(Received October 18, 1952)

REFERENCES

1. McCLEARY, R. A. The nature of the galvanic skin response. *Psychol. Bull.*, 1950, **47**, 97–117.
2. PAINTAL, A. S. A comparison of the galvanic skin responses of normals and psychotics. *J. exp. Psychol.*, 1951, **41**, 425–428.
3. SEWARD, J. P., & SEWARD, G. H. The relation of galvanic skin reactions to preceding resistance. *J. exp. Psychol.*, 1935, **18**, 64–79.

Journal of Experimental Psychology
Vol. 45, No. 6, 1953

ANTICIPATIVE TRANSFER OF MECHANICALLY GUIDED TURNS

GEORGE M. HASLERUD
University of New Hampshire

Little work has been done on manual and mechanical guidance since the much-quoted studies of Carr and his students (**2, 3, 12, 13**) a quarter-century ago. They left the issue in a series of empirical observations (**2,** p. 192): "Guided trials never operated to increase the number of trials requisite for mastery," "Effectiveness of guidance tends to increase the earlier in the learning process it is inserted," "Effectiveness of guidance tends to decrease with the amount given." These tendencies were found much the same for humans as for rats. Other investigators, quite as empirically, found evidence that guidance was not useful under the conditions they employed. Gates and Taylor (**5**) found that preschool children both learned and transferred only half as well with tracing, a mechanical guidance, as with copying of letters. Using large amounts of manual guidance, Waters (**13**) showed that including the guided trials in totaling the number required to reach a criterion, the larger the amount of guidance the worse the record in comparison with the controls.

Since the studies of guidance are limited and since some show advantage and others disadvantage from guidance, an analytical experiment is needed which can serve as a basis for an adequate theory. This is especially pertinent now that for the last half-dozen years Maier and his associates (**9, 10, 11**) have claimed both prophylactic effect and cures by guidance for cases of abnormal fixations. On the basis of their results with manual guidance for both motivated and frustrated groups of rats on a Lashley jumping discrimination problem, Maier and Klee conclude, "Guidance operates primarily to break old responses and is relatively ineffective for new learning" (**11,** p. 150). It is important to examine Maier's method and conclusions because the change of response to an already established pattern is the problem of psychotherapy as well as much other learning. If teachers and psychotherapists are to use mechanical and manual guidance, the relation of guidance to active corrective methods ought to be rechecked.

Purpose

Anticipations or intramaze transfers in free parts of a maze detect sensitively the reactions to patterns in the goal region (**6**). By imposing mechanical guidance for two successive units near the goal, one should be able to determine in the free units whether there is more, equal, or less effect than for a comparable pair of culs-de-sac. To establish the relative dominance one can also pit mechanical guidance for one pair of goal units against trial-and-error avoidance of culs-de-sac on the other side for an adjacent pair. Finally, after a pattern has been established in the free area of the maze, how resistant is it to change by a shift of culs-de-sac or guided paths in the goal region?

Procedure

The elevated rectilinear maze of 12 units, the last four of which are shown in Fig. 1, is an adaptation of the Heron-Drake pattern (**8**) and is described in detail in (**7**). The doors which prevent retracing can be left unlocked to make the unit free, or one can be locked to make a cul-de-sac on that side. For mechanical guidance

a 9 × 12-in. metal sheet, painted black like the rest of the apparatus, was fastened 1 in. from the T joining to block a cul-de-sac. The four goal units were prescribed for various combinations of pairs of guided and problem units as shown in Table 1.

Four rats in each of six groups had the series of patterns diagramed in Part I, and four others had the mirror images. Then for Trials 21–40 each *S* was assigned at random to one of the two patterns for its group outlined in Part II. One should note in Table 1 the guided pair of goal units which continue unchanged from Part I to Part II to provide the common basis for comparison of the effect of guided and problem changes of the other goal pair in Part II.

The 48 naive female white rats, approximately three months of age at the beginning of the experiment, were divided by chance into six groups. Since three died during the nearly two months of the experiment, the calculations are made on 45 complete records. One trial a day was given during both the week of gentling and training to go through a door on a straightaway and the 40 days of experimental trials. The animals found a pinch of dry feed at the end of the last unit and were then transferred for the remainder of the ration to cages immediately behind the goal.

Results

Since the first two units of the maze are greatly influenced by an entrance gradient (6), this study is restricted to patterning and changes in free units three through eight. The tabulations for Groups II–VI are for turns to the same side as prescribed by mechanical guidance in both Parts I and II. Group I, which had four problem units and no guided turns, has an analogous tabulation of turns to the same side as the prescribed path. Six turns in the free units for five days give 30 as the maximal score over a five-day period for any rat. The variance was analyzed for all eight of these five-day periods to determine whether differences between our six groups were greater than differences within groups.

Before proceeding with the general analysis it is first necessary to find out whether the competitive groups, V and VI, show a significant amount of alternation in the free units. The tabulations of change of side from one unit to the next indicate only a chance number of shifts for all groups on the first trial and then a rapid assumption for all but Groups V and VI of single sidedness in the free units. Group V, with the two units closest to the goal guided to one side and the preceding two units with cul-avoidant path on the other side making a double-alternation situation, continued to show chance distribution of alternation for the first 20 trials. Group VI, where the culs-de-sac were at Units 11 and 12, has its distribution somewhat more skewed toward single sidedness. Since no group showed more than a chance amount of alternation, all six groups can be compared on a single variable, the relative preponderance of free turns on the side of the guided (prescribed) goal turns.

Groups I and II for the first 20 trials exhibit single sidedness in the free units to almost an identical degree. On the first five trials the mean for Group I (with culs-de-sac) was 21.3

Fig. 1. Arrangement of blocks and available culs-de-sac in goal units to illustrate setting for Group VI in Part I (see Table 1)

TABLE 1

PRESCRIBED PATHS AT GOAL RESULTING FROM GUIDED (g) AND PROBLEM (p) SETTINGS
(Half of rats had patterns shown and half had the mirror image to balance left and right. Upper case for those units changed in Part II)

Groups....	I		II		III		IV		V		VI	
N.....	8		7		8		7		7		8	
Part I (Trials 1–20)												
Goal Units	L	R	L	R	L	R	L	R	L	R	L	R
12		p		g		g		p		g		p
11		p		g		g		p		g		p
10		p		g		p		g	p		g	
9		p		g		p		g	p		g	
Part II (Trials 21–40)												
12		p		g		g	G			g	G	
11		p		g		g	G			g	G	
10	G		P		G			g		G	g	
9	G		P		G			g		G	g	
or												
12	G		P			g	P			g	P	
11	G		P			g	P			g	P	
10		p		g	P			g		P	g	
9		p		g	P			g		P	g	

and for Group II, 21.9, and for successive five trials the means of the two groups are respectively, 27.3, 27.9; 28.0, 28.4; and 27.3, 28.3. Since at no point is there a significant difference between the groups, and they both near the maximal score of 30, one must conclude that naive rats with no previous pattern perceive (anticipate) a passive mechanically guided turn near the goal as no different from a similar active turn to avoid a cul-de-sac.

When in the last half of the experiment, as shown in Part II of Table 1, Group II had two of its blocked goal units continue guided and the other two made problem choices to the opposite side by the use of culs-de-sac, the free-unit turns to the guided side dropped from 28.3 to 25.1, 21.9, 18.6, and 12.3 on successive groups of five trials. By Trials 31–35 the score differed significantly beyond a p of .01 compared with the 16–20 one, the last before the goal shifts. By Trials 36–40 the F gives a p beyond .001.

No such significant change occurred, however, in Group I when two of the goal units were blocked to guide the rat to the opposite side where the culs had been in Part I. The resultant changes of sidedness in the free units were so small that none of them gives a p as little as .05. Apparently the perception of the goal situation was constant enough to maintain the structuring established by the first 20 trials. If goal turns are modified only by mechanical guidance, the perception formerly built up is apt to continue; if the changes require active elimination of culs-de-sac, the anticipatory perceptions change rapidly too.

Figure 2 portrays the results for the last four groups. One can see that for Groups III and IV the curves for the first 20 trials are very similar to those just presented for the first two groups. The combination of two culs-de-sac and two mechanically blocked turns to one side at the goal patterns the free units to a sidedness significantly beyond chance after the first

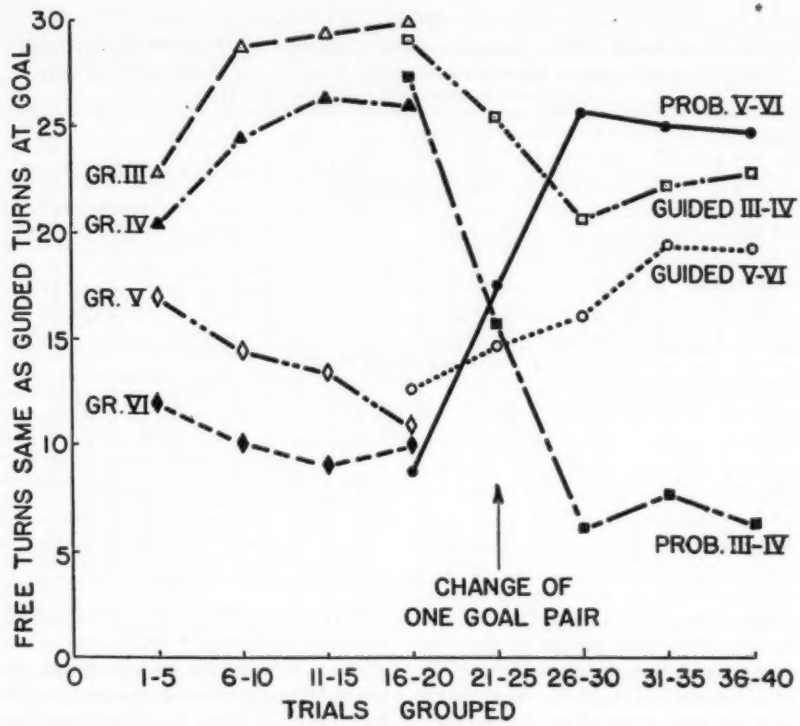

FIG. 2. Sensitivity of free units to guided and problem settings at goal on original, Part I, and adjustive, Part II, learning

five trials. Since Group III with the guided turns next to the goal is not significantly different from Group IV with its guided turns at units nine and ten, the groups were combined for Part II. All were placed in a situation potentially competitive as contrasted with the single sidedness of the first part. Half of each group had its two noncontinuing goal units guided to the opposite side by blocks; half, actively by culs-de-sac. The mean scores for the new combined groups were recalculated for Trials 16–20 as the base from which the curves for the trials after goal modification can be compared. The designations "Guided" and "Problem" at the right of the figure are for the reconstituted groups.

The dramatic drop from 27.3 to approximately 6.5 turns for the cul-avoidant group is to be contrasted with the insignificant drop from 29 to around 22 turns for the mechanically guided group. The F for the problem group has a p beyond the .01 level for even the first five trials after goal change and p's beyond .001 for the later groups of five trials. At no time did the guided group change the free units significantly from their former structure. These results agree well with those found for Groups I and II.

The obviously slow drift from a chance sidedness of 15 for Groups V and VI demonstrates, however, that a real competition can exist between guided and problem goal turns. That

the direction is downward for both groups, away from agreement with guided goal-unit turns, shows the slightly stronger effect of the culs-de-sac. That the groups after 20 trials had neither reached a stable (beyond chance) pattern of single sidedness nor single alternation would suggest a perception in *S* of a confused goal arrangement with probably some kinesthetic stimulation from both sides. The lack of any significant difference between Groups V and VI made it feasible to combine them as has been explained for Groups III and IV for the rearrangements of Part II. When the goal units were made noncompetitive on Trial 21, the perception of confusion (free units near chance level of turns) continued for only the guided group. The average problem-group score after the first five trials of change rose to the 25 level, with *p*'s in the neighborhood of .001 compared with the base level of 8.5 during Trials 16–20.

Discussion

More objective than VTE's, the anticipatory turns in the free units portray visibly *S*'s perception of the kind of situation in the goal region. The results indicate that as long as an initial perception of a new situation is in the making, mechanically guided turns are as effective as those resulting from trial-and-error. Any subsequent correction or modification of that original perception requires the active discrimination of alternatives. It would not be easy to discover these principles except with free maze units, but once observed, they can be applied and used for prediction in a wide variety of cases.

While our experiment found little value in mechanical guidance for restructuring of what has been learned, such guidance was as good as, and under certain situations might be even better than, active trial-and-error for initial learning. Carr and Koch's (2) *S*s, both animal and human, showed guidance of all types effective when early and in small amount (e.g., during the initial adjustment to their maze, interspersing of two guided trials within the trial-and-error trials, was more efficient than straight use of culs-de-sac). The naive *S* can probably profit from a few mechanical or manual puttings-through at the beginning of his learning of a complicated skill. It is possible, too, that the child, because of his smaller apperceptive mass, may be able to benefit from more guidance than adults.

Carr and his associates found that a large amount of guidance was deleterious for later independent learning. Since our results show guidance effective only during the formation of expectations concerning goal organization, one can see that too much guidance will either build up interferences to subsequent learning or at best represent just so many waste trials. The interferences are well brought out in Tsai's (12) experiment on gradual versus abrupt withdrawal of guidance in maze learning. Waters (13) found increasing inefficiency with increasing amounts of guidance, but the reason he found no actual interference was probably that he was using manual guidance with human adults. With animals or children interference might be expected. If Gates and Taylor (5) had tested the children after the first or second session instead of after five daily sessions, they would probably have found the tracing group at least as good if not actually better than the copying one. Carrying the mechanical guidance beyond the optimal point leads to expectations of behavioral support with consequent frustration when the support is removed, just as Gates and Taylor describe for their tracing group on the test trials.

Although conceiving the role of guidance as different for initial and adjusted learning fits well and helps to explain practically all prior studies, it seems to clash directly with Maier's "Guidance is primarily effective for breaking a fixation and relatively ineffective for establishing a new response" (11, p. 155). Too much initial guidance (30 trials) accounts certainly for part of the inefficiency observed on new learning in one group; when adjustment was made by Maier and Klee for this factor, the learning scores for trial-and-error and guidance were much the same. This was also true for total scores where guidance and trial-and-error were alternated. Also important is the fact that they were using manual guidance while the present experiment's conclusions are based on mechanical guidance. Fields (4) apparently finds manual guidance a useful technique to get rats to jump at the positive card in the preliminary training for his multiple-discrimination problem. Bernstein (1) has recently reported that pre-experimental and continued handling of animals greatly changes their flexibility. Moreover, Carr (2) observed that in his

human *Ss* manual guidance was associated with a much more passive attitude.

Our experiment is equally concerned with the first part of Maier's statement. The breaking of an old response on the Lashley jumping apparatus after the correctness ratio had been made 50% provided a highly charged emotional situation. Since manual guidance could very well recondition the emotional supports of the preliminary training, Maier's findings on the value of guidance for breaking stereotypes may be due more to the emotional adjustment than to the guidance function as such. If Maier's results give experimental support to directive therapy, as he infers, then our results should raise some doubts about the effectiveness of pure directive (mechanical) methods for breaking habits.

Summary

Differences in anticipatory turns in the free first eight units of a 12-unit rectilinear maze were related to the various arrangements of pairs of guided and problem settings in the four goal units. Six groups of eight rats had one trial a day for 20 days on initial pattern. Then 20 days of one trial a day tested the change in the free units after a shift of one of the two goal pairs to the opposite side. Through analysis of variance of scores on successive groups of five trials for each rat, statistically significant support was found for two conclusions: For naive *Ss* mechanical guidance at the goal transfers to the free units just as effectively as active trial-and-error. To modify turns already structured in the free area, however, only forcing an adjustment by putting a cul-de-sac in the former pathway was effective. Comparable readjustment by mechanical blocking did not change turns in free units significantly; such goal changes seemed not perceived.

These principles help to explain the apparently contradictory results in prior studies of guidance. While Part I of this experiment makes plausible the expectation of good results from a few guided trials at the beginning of learning for naive subjects or children, Part II raises doubts about the efficiency of guidance or putting-through to change established habits and perceptions. The implications for psychotherapy ought to be tested.

(Received September 24, 1952)

References

1. Bernstein, L. A note on Christie's: "Experimental naïveté and experiential naïveté." *Psychol. Bull.*, 1952, **49**, 38–40.
2. Carr, H. A. Teaching and learning. *J. genet. Psychol.*, 1930, **37**, 189–219.
3. Carr, H. A., & Koch, H. Influence of extraneous controls in the learning process. *Psychol. Rev.*, 1919, **26**, 287–293.
4. Fields, P. E. The effects of ionizing radiation upon physical and psychological capacities in various species. I. The efficiency of the serial multiple visual discrimination apparatus and method in the white rat. USAF School of Aviation Medicine, Project No. 21-47-003, Report No. 1, 1952.
5. Gates, A. I., & Taylor, G. A. The acquisition of motor control in writing by preschool children. *Teach. Coll. Rec.*, 1923, **24**, 459–468.
6. Haslerud, G. M. Transfer of single alternation pattern in relation to goal and entrance maze gradients. *J. Psychol.*, 1945, **20**, 259–269.
7. Haslerud, G. M. Properties of bi-directional gradients at subgoals. *J. genet. Psychol.*, 1949, **74**, 3–16.
8. Heron, W. T. An automatic recording device for use in animal psychology. *J. comp. Psychol.*, 1933, **16**, 149–158.
9. Maier, N. R. F., & Ellen, P. Studies of abnormal behavior in the rat: The prophylactic effects of "guidance" in reducing rigid behavior. *J. abnorm. soc. Psychol.*, 1952, **47**, 109–116.
10. Maier, N. R. F., & Feldman, R. S. Studies of abnormal behavior in the rat: XXII. Strength of fixation and duration of frustration. *J. comp. physiol. Psychol.*, 1948, **41**, 348–363.
11. Maier, N. R. F., & Klee, J. B. Studies of abnormal behavior in the rat: XVII. Guidance versus trial and error in the alteration of habits and fixations. *J. Psychol.*, 1945, **19**, 133–163.
12. Tsai, L. S. Gradual versus abrupt withdrawal of guidance in maze learning. *J. comp. Psychol.*, 1930, **10**, 325–330.
13. Waters, R. H. The influence of large amounts of manual guidance upon human maze learning. *J. gen. Psychol.*, 1930, **4**, 213–228.

Journal of Experimental Psychology
Vol. 45, No. 6, 1953

WARM-UP EFFECT IN HUMAN MAZE LEARNING

C. E. HAMILTON
Alfred University
AND W. R. MOLA
Montana State University

Studies concerned with the learning of verbal materials have led to conflicting results with regard to the effect of the presumed warm-up variable. It has been indicated that an appropriate set-inducing activity prior to original learning or relearning may benefit the learning which follows it (**2, 5, 10**). However, more recent investigations fail to confirm at least part of these earlier findings (**4, 6**). In addition, studies employing motor-learning tasks have proven inconsistent with those employing verbal-learning materials. Of these, no study reports any alteration of the rate of original learning on the rotary-pursuit task due to preceding warming-up practice although a number of different types of warm-up activities have been used (**1, 3, 7, 8, 9**). Further, for the rotary pursuit, relearning may be affected adversely instead when such activity intervenes during a rest interval (**8, 9**). One investigator (**7**) using the alphabet-printing task has, however, shown facilitation of relearning when an appropriate set-maintaining activity fills part of the rest interval.

In view of the foregoing inconsistent findings it is felt that the study of tasks on the verbal-motor dimension other than those already employed may shed further light on the effect of preliminary activities on learning. The purpose of the present study is to explore a previously unstudied point on the verbal-motor dimension in this regard. The finger-relief maze task was selected as appropriate in view of the fact that it exhibits clear aspects of both verbal and motor learning and therefore stands intermediate to the rotary-pursuit task on the one hand and the memory drum on the other.

METHOD

Subjects.—The *S*s were 45 male and 30 female undergraduate students enrolled in psychology courses at Montana State University. All were naive with respect to the purpose of the experiment. They were assigned to one of the three conditions of the experiment, based on the order of their appearance, and each of the three groups contained 15 male and 10 female *S*s, respectively.

Materials.—Six multiple-U finger-relief mazes were employed in the experiment. Of these, five were designated as preliminary mazes for use in Cond. B and C, below, and the sixth was designated as the test maze, its use being common to all three conditions.

Each maze was constructed by forming 3/32-in. sections of wire rod into U-shaped units 2¾ in. across the base and having 1-in. verticals. These units were set at the surface of a ¼-in. plywood board 18 in. square. The terminus of either the right or left vertical of each unit bisected the base of the next unit to form the continuous path with the alternate vertical in each case being the blind alley. A 1-in. section of rod formed the starting alley leading to the first choice point. Each maze contained 16 choice points, the correct path turning 8 times to the right and 8 to the left. No two mazes had the same pattern, the patterns being composed at random subject to the restriction of equal numbers of right and left turns. A "sample" unit corresponding to the starting alley and the U it led to was placed at the right-hand corner of one of the mazes; this

[1] A table giving data for each of the three conditions has been deposited with the American Documentation Institute. Order Document No. 3920 from American Documentation Institute, Auxiliary Publications Project, Photoduplication Service, c/o Library of Congress, Washington 25, D. C., remitting $1.25 for microfilm (images 1 inch high on standard 35 mm. motion picture film) or $1.25 for photoprint readable without optical aid.

was employed during the preliminary instructions to acquaint *S*s with the problem and give better comprehension of the instructions.

Blackout goggles were used to blindfold *S*s. They were not permitted to see any of the mazes at any time. A line drawing showing a hand with the index finger alone extended and following a section of such a maze was displayed during the first part of the directions before blindfolding *S* in order to secure uniformity in the manner of contacting the raised alleyways.

Procedure.—Each *S* was assigned to one of the three conditions and performed according to the sequence for that condition. *Condition A:* 15 trials on Maze 6 (test maze); *Condition B:* one trial each on Mazes 1 through 5, followed immediately by 15 trials on Maze 6; *Condition C:* 1 trial each on Mazes 1–5 followed 24 hr. later by 15 trials on Maze 6. These conditions are further designated as the control, warm-up, and general practice conditions, respectively.

Detailed written instructions were read to each *S*. These consisted of the same general instructions for all three conditions, and appropriate special instructions for each separate condition.

All *S*s were instructed to employ a "verbal" approach, i.e., try to remember an R–L–R–R, etc. pattern during each trial. The *E* guided *S*'s hand to the starting point for each trial and signaled *S* when to begin. He informed *S* when the end of each maze was reached. In this connection, the final right-hand alley was considered the terminal point of each maze. The *S* was instructed to return his hand to his lap at the completion of each trial and wait for *E*'s next command. The *S* was not permitted to touch the maze except with the tip of his index finger during performance (*S*s used their preferred hand).

Performance was recorded in terms of errors and time for each trial. The *S*s were instructed as to both these measures and encouraged to make the best speed consistent with reducing errors. Approximately a 5-sec. interval occurred between trials on the test maze while *E* recorded the time for the concluded trial from a stopwatch. Longer intervals occurred between the single trials on the preliminary mazes while these were being changed; this interval was not timed carefully but involved approximately an additional 5 sec.

Results and Discussion

The present study permits a comparison between learning on the finger maze both with and without the bene-

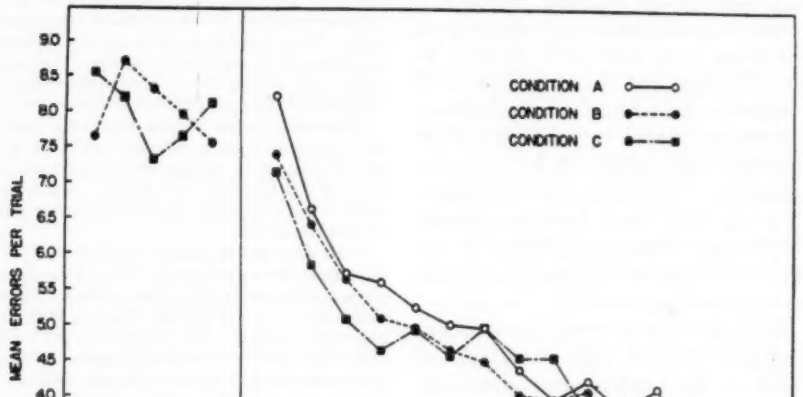

Fig. 1. Mean errors for the single trial on each preliminary maze and on 15 trials on the test maze

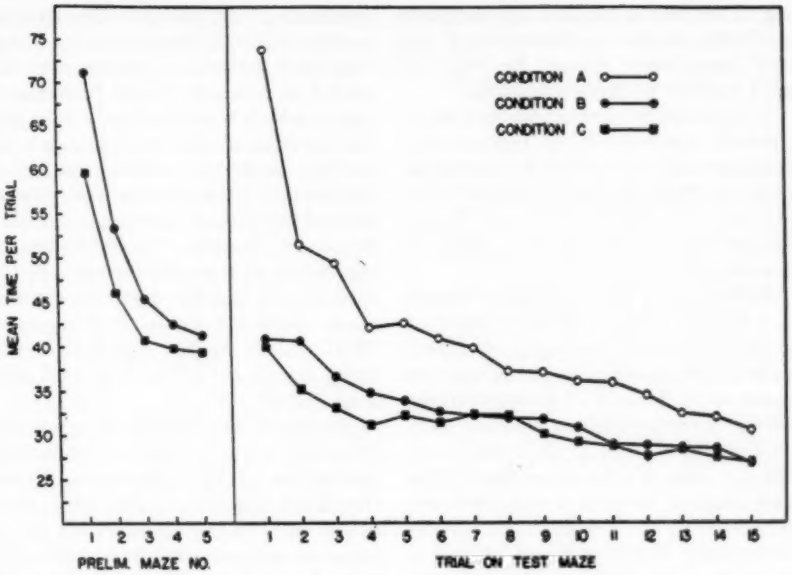

FIG. 2. Mean time-per-trial scores for the single trial on each preliminary maze and on 15 trials on the test maze

fit of immediately preceding activity of a similar nature. Further, it permits some evaluation of the duration of such effects as might result from the preliminary activity. The essential findings of the experiment are shown graphically in Fig. 1 and Fig. 2.[1] In the first part of Fig. 1 there are shown the average errors for the single trials on each of the five preliminary mazes for Cond. B (warm-up) and C (general practice), Cond. A (control) not being represented because *Ss* did not practice on the preliminary mazes in this condition. In the second part of Fig. 1 are shown the average errors for 15 trials on the test maze for all three conditions. In this figure the ordinate represents mean errors and the abscissa, maze number during the preliminary practice, and learning trial on the test maze.

Inspection of Fig. 1 reveals no obvious initial difference between *Ss* in Cond. B and C. The averages center around the value 8.00 and show no consistent tendency to increase or decrease. On the test maze, which permits comparison of the rate of learning among the three conditions, Cond. C appears to exhibit the most rapid reduction of errors during the first five trials while Cond. B shows the next most rapid reduction during the same period. Beyond the first five trials, however, no consistent differences are exhibited among the three conditions. To evaluate the differences noted for the first five trials, the average errors for these trials were determined for each condition and subjected to simple analysis of variance. The value of F obtained was less than one and obviously not significant. Hence, although the error measures appear to yield evidence that practice on the preliminary mazes results in an initially more rapid learn-

ing of the test maze, such an outcome evidently is due to chance and the null hypothesis cannot be rejected with respect to these measures.

It is pertinent to note also that while the error measures do not indicate any positive warm-up effects for the maze task, neither do they indicate that practice on the preliminary mazes yielded any general practice effect in this respect.

Referring to Fig. 2, which presents in a similar manner the data relevant to the average time measures obtained, it should be noted that the means are based on 24, 25, and 22 *Ss* respectively for the three conditions whereas data were obtained from 25 *Ss* in each condition. The *N*'s for these conditions were reduced because it was observed in comparing the average time for the preliminary mazes in Cond. B and C that these two conditions differed considerably. Simple analysis of variance applied to the means for these two conditions yielded an *F* of 6.82, which with 1 and 48 *df* is significant at the 5% level. Since the corresponding measures for the trials on the test maze would be meaningless in the face of such an initial inequality, it was decided to eliminate from the analysis of these data all *Ss* who took more than 2 min. for either the first preliminary maze (in Cond. B and C) or the first trial on the test maze (in Cond. A, only). This resulted in discarding *Ss* to yield the group *N*'s noted. A second analysis of the means for Cond. B and C on the five preliminary mazes yielded an *F* of 3.58 which is not significant at the 5% level, 4.06 being required.

With the data thus modified, inspection of the mean time-per-trial scores for the three conditions reveals obvious differences between the control condition and the two experimental conditions. In general, the two experimental conditions exhibit a reduction of time-per-trial scores over the period of practice on the preliminary mazes which is seen to carry over into the practice on the test maze in comparison with the control condition. Differences between the two experimental conditions are much smaller, however. Simple analysis of variance applied to the means for each condition on the first five trials on the test maze yielded a value of *F* equal to 28.21 and is highly significant, 4.92 being significant at the 1% level with 2 and 68 *df*.

In view of the significant value of *F* obtained, *t* was employed for further evaluation of the differences among the three conditions, the error term being derived from the within-group variance estimate obtained in the analysis of variance. The *t* for the mean differences between the control condition (A) and each of the two experimental conditions was significant beyond the 1% level, but *t* for the mean differences between the two experimental conditions was not significant at the 5% level. Hence, while these two conditions appear to differ significantly from the control condition, it is evident that they do not differ significantly from each other.

These findings yield the essentially negative conclusion that warm-up effect has not been demonstrated for the finger-relief maze. Practice on the preliminary mazes, while not affecting the errors made in learning the test maze, apparently reduces the time needed to perform on this latter task. This effect is not of a warm-up character, however, since it is as evident in Cond. C where a 24-hr. period intervened between the preliminary mazes and the test maze as in Cond. B where the test maze followed the pre-

liminary mazes immediately. Such an outcome can be attributed only to general practice effect and is probably due to increased familiarity on the part of *S*s with the kind of task presented, gained during the preliminary practice. These results further support Ammons' (1) earlier conclusion that verbal and motor performances are affected differently by prepractice warming-up activities, insofar at least as warm-up effects may be accepted for verbal learning.

Summary

In an experiment designed to determine the possible effect of warming-up activity on the learning of a task different from those previously employed, three groups of 25 *S*s learned a multiple-U finger-relief maze for 15 trials each. One group, serving as a control, learned this maze without preceding practice; the other groups had one trial on each of five similar preliminary mazes, such practice being followed either immediately by work on the test maze for one group or 24 hr. later, for the other. Results showed no significant differences among the groups with respect to errors on the test maze. Both experimental groups were superior to the control with respect to time-per-trial scores but not significantly different from each other. It was concluded that the experiment does not afford evidence for warm-up effect in the learning of the finger-relief maze.

(Received October 24, 1952)

References

1. Ammons, R. B. Effects of various pre-practice activities on rotary pursuit performance. *J. exp. Psychol.*, 1951, **41**, 187–191.
2. Hamilton, C. E. The relationship between length of interval separating two learning tasks and performance on the second task. *J. exp. Psychol.*, 1950, **40**, 613–621.
3. Hamilton, C. E. Ocular pursuit and performance on the rotary pursuit. *Perceptual and Motor Skills Res. Exch.*, 1952, **4**. (Abstract)
4. Hovland, C. I., & Kurtz, K. H. Experimental studies in rote learning theory: IX. Influence of work-decrement factors on verbal learning. *J. exp. Psychol.*, **42**, 265–272.
5. Irion, A. L. Retention and warming-up effects in paired-associate learning. *J. exp. Psychol.*, 1949, **39**, 669–675.
6. Rockway, M. R., & Duncan, C. P. Pre-recall warming-up in verbal retention. *J. exp. Psychol.*, 1952, **43**, 305–312.
7. Silver, R. J. Effect of amount and distribution of warming-up activity on retention in motor learning. *J. exp. Psychol.*, 1952, **44**, 88–95.
8. Spiegel, J. Effect of visual practice on rotary pursuit performance. *Motor Skills Res. Exch.*, 1951, **3**, 4. (Abstract)
9. Spiegel, J., & Ammons, R. B. The effects of ocular practice on subsequent rotary pursuit performance. *Motor Skills Res. Exch.*, 1950, **2**, 54. (Abstract)
10. Thune, L. E. The effect of different types of preliminary activities on subsequent learning of paired-associate material. *J. exp. Psychol.*, 1950, **40**, 423–438.

Journal of Experimental Psychology
Vol. 45, No. 6, 1953

SATIATION IN A REVERSIBLE PERSPECTIVE FIGURE

V. R. CARLSON[1]
The Johns Hopkins University

When one fixates a visual figure steadily for a time and then looks at another figure, certain distortions in the form or location of the second figure may occur. Köhler and Wallach (**6**) describe these "figural aftereffects" extensively for plane figures and develop a theory to explain the phenomenon. The physiological process involved is called "satiation." Köhler and Wallach suppose this process to be an increase in resistance to the flow of electrical currents in the cortex. But operationally, satiation refers to the process underlying figural aftereffects, whatever it may be. In this sense, a figure becomes "satiated" whenever it has been fixated for a number of seconds, and the degree of satiation increases as the fixation period is prolonged.

Köhler and Emery (**5**) report that figural aftereffects are just as evident with three-dimensional figures as with plane figures. For one thing, satiation of a three-dimensional figure subsequently induced apparent depth in a plane figure. Further, the induced depth was opposite in direction to that of the satiating figure. Now this is quite similar to what happens in reversible perspective, except that instead of two different figures we have two alternative perceptual responses to the same figure. The reversal is a reversal in the apparent third-dimensional relations of the figure. Although one may not be subjectively aware of it, a point which appears to be "in front" before a reversal will appear to be "in back" after the reversal.

It is this change in the apparent location of points in the third dimension which makes reversible perspective analogous to the effects investigated by Köhler and Wallach. Figural-aftereffect displacement in the third dimension appears to follow the same principles as in a single plane, according to Köhler and Emery.

Köhler (**4**, p. 72) and Köhler and Wallach (**6**, p. 270) have offered the hypothesis that satiation induces reversal in a reversible figure-ground organization. Briefly, as the cortical "figure-process" associated with one alternative of the figure becomes more and more satiated, it reaches a point where it becomes "blocked" and the other alternative comes into phase. One of the arguments for this hypothesis is the observation by Köhler that certain *S*s show an increasing rate of fluctuation as fixation of a reversible figure-ground is prolonged. Presumably the induced satiation is not dissipated as fast and as completely as it is built up from reversal to reversal. That is, it takes less and less time for each figure-process to become blocked. However, Köhler himself points out that some *S*s show increasing rates of fluctuation but other *S*s do not.

Hochberg (**3**) has tested the hypothesis by a procedure directly comparable to that generally used in figural-aftereffect experiments. He satiated one alternative of a reversible *figure-ground* by presenting that alternative alone for a period of fixation. With subsequent fixation of the reversible pattern, the opposite alternative tended to predominate over the satiated alternative.

[1] The author is indebted to Dr. C. W. Eriksen of The Johns Hopkins University for many helpful criticisms and suggestions.

The present investigation is similar to Hochberg's except that a reversible-*perspective* figure was used and the possibility that the results might be explained in terms of a "suggestion" effect irrelevant to the concept of satiation was explored. The question to be answered is whether prior satiation of one alternative of a reversible-perspective figure will depress that alternative in favor of the other. A first criterion for such "depression" is that the nonsatiated alternative should tend to appear first upon subsequent fixation of the reversible figure. A second criterion is that the nonsatiated alternative should predominate relatively longer in time during each cycle than the satiated alternative, at least over the first few cycles. If we let A equal the duration of alternative A during the first few cycles, as recorded by *S*'s response, and B equal the duration of alternative B, then the quantity A–B should be greater when alternative B has been previously satiated than when neither alternative has been satiated. And A–B should, even more so, be greater when alternative B is satiated than when alternative A is satiated. This is the prediction made in the present experiment, and no assumptions are made concerning the absolute magnitudes of A and B.

Procedure

The test figure (T) was an elliptical ring bisected by a shaft. The figure can be seen, in apparent three-dimensionality, as a circular ring with the shaft projecting through it. When viewed steadily, the apparent orientation of the ring shifts back and forth from "right" (R) to "left" (L) or, when the entire figure is rotated 90°, from "up" (U) to "down" (D). This figure was chosen because a corresponding figure which would not readily reverse could be simply constructed for each of its alternatives.[1] These are the "inspection (or satiating) figures" (I–R, I–L, I–U, I–D). Two control inspection figures were also used (I–CRL, I–CUD), which favored neither R nor L nor U or D. The stimulus figures are shown in Fig. 1.

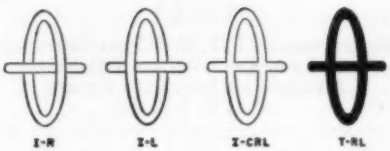

Fig 1. The RL inspection figures (*I*) and test figure (*T*). The UD figures are the RL figures rotated 90 degrees and used as a separate set of figures.

Each *S* was first of all made thoroughly aware of the reversible behavior of the T-figure. By means of a three-dimensional model he was instructed as to which apparent orientation of the ring was to be called "R," which "L," etc. Then viewing the T-figure he practiced pressing a telegraph key with the right hand when "R" (or "U") was in phase and another telegraph key with the left hand when "L" (or "D") was in phase.

During an experimental trial, an I-figure was presented for 15 sec. The *S* made no response to the I-figure other than to fixate its center and avoid eye or head movements as much as possible. At the end of 15 sec., with no warning, the T-figure was substituted for the I-figure. Figures I–R, I–L, and I–CRL were always followed by T–RL; figures I–U, I–D, and I–CUD by T–UD. The *S* then reported the subjective fluctuations of the T-figure by pressing the telegraph keys in alternation until two complete cycles (RLRL, LRLR, UDUD, or DUDU) had been recorded and the T-figure removed. Before beginning the experimental trials, *S* practiced the procedure with a small cross taking the place of the I-figure.

After each trial, *S* rested for 2 min. before the beginning of the next trial. In all, 12 experimental trials were given, 2 for each I-figure. The particular order of presentation was random for each *S*, except that the UD figures were alternated with the RL figures and no I-figure was repeated until all the I-figures had been presented once.

The figures were projected on a white opaque glass screen placed 3½ ft. in front of *S*. The outside dimensions of the ellipse were 4⅞ × 1¾ in. and it was 5/16 in. wide. The shaft was 3¼ in. long and ⅜ in. wide. The telegraph keys activated the markers of a kymograph driven by a constant-speed motor. From the kymograph tape it could be ascertained which alternative of the T-figure occurred first and the duration of

[1] The figure could probably be improved by changing the "ring" to a "rim."

TABLE 1

FREQUENCIES OF R, L, U, D FIRST-RESPONSES TO TEST FIGURES T-RL AND T-UD AFTER SATIATION ON INSPECTION FIGURES I-R, I-L, I-U, I-D

First Trial				Second Trial			
		I-L				I-L	
		R	L			R	L
	L	47	10		L	40	6
I-R				I-R			
	R	11	7		R	22	7
	$\chi^2 = 28.17$*				$\chi^2 = 21.79$		
		I-D				I-D	
		U	D			U	D
	D	45	13		D	46	15
I-U				I-U			
	U	12	5		U	9	5
	$\chi^2 = 30.42$				$\chi^2 = 31.37$		

* $p = .001$ at $\chi^2 = 10.83$.

each half-cycle for the two complete cycles allowed.

Twenty-six male college students served as *Ss* with the procedure outlined above. In order to obtain a larger *N* for the "first-response" data, 75 additional male college students were used with a similar but simplified procedure. Instead of pressing telegraph keys, these *Ss* wrote down on a slip of paper the way they first saw the T-figure on each trial after having fixated an I-figure for 15 sec. These *Ss* were tested in groups of from 6 to 10 individuals. A larger screen was used, the dimensions of the figure quoted above being approximately tripled, and the distance between *S* and the screen varied with his location in the room.

In addition, two other groups of *Ss* were tested with these same procedures but with a meaningfully ambiguous figure. The purpose of these two additional experiments will be explained later.

RESULTS

The first prediction from the satiation hypothesis is that the nonsatiated alternative should appear first. For example, after fixating I–R, *S* should see L first when he fixates T–RL (refer to Fig. 1).

Table 1 shows the most important comparisons in the first-response data. The values in the cells refer to the frequency of R, L, U, or D first responses to T–RL or T–UD after satiation on I–R, I–L, I–U, or I–D ($N = 75$). Clearly the nonsatiated alternative tends to appear first. In addition, three-way comparisons (not shown here) were made, involving the first responses to the control I-figures (I–CRL, I–CUD). Cochran's chi-square test for correlated frequencies in more than two categories (**2**) was used, and the analysis leads to the following conclusion: A given alternative tends to appear first least often when it has been previously satiated, more often when neither alternative has been satiated, and most often when the opposite alternative has been satiated. This over-all trend is so consistent throughout the data that there can be little doubt that it is definite and reliable.

There is the possibility, however, that the experimental procedure may have set up some attitude, set, or expectancy in the *Ss* which led to the obtained result independently of the "satiation effect" being studied. To *Ss* not knowing the purpose of the experiment, the procedure would seem to indicate an experiment on "suggestion." If *S* took the attitude that he was not suggestible, he might tend to favor the alternative in the T-figure which was opposite to the one presented for satiation in the I-figure. Such a "contrasuggestive" effect, if it occurred, might well have led to the result obtained.

Accordingly a comparable group of 120 *Ss* were tested with the well-known wife-and-mother-in-law figure (**1**), in which the reversal involves a change in "meaning" *but not in apparent depth or perspective.* Here the two alternatives were designated "old woman" (O) and "young woman" (Y). One version, I–Y, was designed so that only the young woman could be seen. Another version, I–O, was designed so that only the old woman could be

TABLE 2

FREQUENCIES OF Y AND O FIRST RESPONSES TO TEST FIGURE T–OY AFTER SATIATION ON INSPECTION FIGURES I–Y AND I–O

First Trial				Second Trial			
		I–O				I–O	
		Y	O			Y	O
	O	15	9		O	8	18
I–Y				I–Y			
	Y	49	47		Y	39	55
	$\chi^2 = 15.50^*$				$\chi^2 = 35.06$		

* $p = .001$ at $\chi^2 = 10.83$.

seen.[3] The *S*s were first made thoroughly aware of the ambiguous nature of the test figure (T–OY) and then satiated on I–Y and I–O, separately. In each case they reported their first responses to the ambiguous test figure. A small cross was used for a control I-figure. Presumably if the procedure introduced a contrasuggestive effect with the ring figure in the first experiment, it would also introduce such an effect here.

Table 2 gives the frequencies of first responses to T–OY after previous fixation for 15 sec. upon I–Y and I–O, respectively. These data were evaluated in the same way as those obtained with the ring figure. Again the differences are highly significant, but they are *opposite* in direction to those of the ring figure. Here previous satiation of one alternative tends to favor the appearance of that same alternative as the first response to the ambiguous figure. This result can be interpreted as some kind of suggestion effect but certainly not as a contrasuggestive effect. Probably there was less suggestion of any kind with the simpler ring figure, but if the procedure had introduced any such effect, we would expect it to have operated in the direction opposite to the trend of the results obtained.

The second criterion which would indicate depression of the satiated alternative in the original ring figure would be the relative decrease in duration of that alternative. Let R equal the average duration of alternative R during the first and second cycles of *S*'s response to figure T–RL. The duration of any alternative in each cycle is the amount of time which elapsed from the moment *S* signalled the appearance of that alternative to the moment he signalled the appearance of the other alternative. This measure may or may not include a "period of uncertainty" on *S*'s part, and it takes no account of which alternative appeared first. Similarly, L equals the average duration of alternative L (in figure T–RL) for both cycles, U equals the average duration of alternative U (in T–UD) for both cycles, and D equals the average duration of alternative D (in T–UD) for both cycles. The hypothesis, then, would require that the quantity R − L be least after previous fixation of inspection figure I–R, intermediate after previous fixation of I–CRL, and highest after previous fixation of I–L. Similarly U − D should be least, inter-

TABLE 3

MEAN R–L VALUES (LEFT HALF OF TABLE) AND U–D VALUES (RIGHT HALF OF TABLE) IN SECONDS

Measure	Test Figure T–RL			Test Figure T–UD		
	I–Figure			I–Figure		
	I–R	I–CRL	I–L	I–U	I–CUD	I–D
Mean	−.70	.11	.92	−.96	.16	1.38
SD	2.49	1.73	3.86	2.65	3.06	2.30

[3] As it turned out, I–Y was seen only as the young woman, but I–O merely favored perception of the old woman more than perception of the young woman. Also there seemed to be a general preference for perceiving the ambiguous figure as the young woman. Both of these effects are discernible in the data obtained, but they do not modify the conclusion drawn.

TABLE 4

ANALYSIS OF VARIANCE SUMMARY FOR THE UD DATA

Source	*df*	*VE*	*F*
I–Figures	2	71.85	4.95**
Ss	25	23.41	1.61*
I–Figures × *Ss*	50	11.40	
Error	78	14.51	
Total	155		

* $p = .05$.
** $p = .01$.

mediate, and highest after previous fixation of I–U, I–CUD, and I–D, respectively. Table 3 gives the mean R−L and U−D values for each category ($N = 26$).[4]

Two analyses of variance were undertaken for these scores, one for the UD data and another, parallel analysis for the RL data. Each analysis is a double classification (inspection figures and subjects) with two scores per cell (two trials under the same condition). Table 4 shows the results of the analysis of variance for the UD data. The inspection-figure means differ in the predicted direction, and the variance between them is significant at the .01 level of confidence. There is much variability in the data, however, and many exceptions to the over-all trend in individual trials.

The same kind of analysis for the RL data showed the variance between the inspection-figure means to be significant at the .05 level of confidence. But unfortunately this test cannot be accepted, since the error term proved not to be distributed homogeneously and no transformation of the scores proved satisfactory. About all that can be said for this set of data is that the means are in the predicted direction. Much more detailed analyses of both the UD and RL data were made, but they yielded little of importance beyond the results already indicated.

Similar time scores, using the same procedure, were obtained from 20 *Ss* on the young-woman-old-woman figure previously mentioned. Here no satiation effects were expected, and none were found. Again, the reason for obtaining the data with this figure was to make sure that the procedure used was not biasing the results in favor of the hypothesis through what may be called some kind of suggestion effect.

DISCUSSION

These results obtained with a reversible perspective figure are essentially the same as those found by Hochberg (**3**) for a reversible figure-ground. In both cases prior satiation of one alternative of the reversible pattern caused the other alternative to predominate over the satiated alternative. This finding agrees in general with Köhler's hypothesis that satiation may induce the reversals in a reversible figure. However, there are several things to be considered.

First of all, the relative diminution in duration of the satiated alternative needs substantiation and much more careful working out. The effect is not very clear-cut and definite, at least in the present results. Three possible sources of attenuation may immediately be pointed out. First, the satiation time used (15 sec.) may not have been an optimum one. Second, the inspection-figure alternative was not exactly the same kind of figure as the corresponding alternative in the reversible figure. It has to be somewhat different, if one is working with a reversible-perspec-

[4] Each individual difference score has been corrected for the mean control first-phase-minus-second-phase difference in both the first and second cycles. There was a tendency (in the control condition) although statistically insignificant for the alternative occurring first, regardless of what it was, to last slightly longer than the alternative occurring second. Since the non-satiated alternative occurred first in approximately two-thirds of the observations, this effect constituted a bias in favor of the hypothesis. The net effect of the correction was to reduce the original differences between the means in Table 3 but not enough to change any conclusions from the analysis.

tive figure; otherwise, the inspection figure itself would reverse. Third, most of the *Ss* reported that the fluctuations of T–RL were less clear-cut than those of T–UD, and they experienced greater difficulty in reporting the reversals of T–RL. Perhaps the heterogeneity of the error variance in the RL data is related to this greater uncertainty.

But in addition to verification of the relative-duration effect, we need a precise working out of the actual durations of each alternative and the periods of uncertainty during the course of *S*'s response to the reversible pattern. Perhaps this can be accomplished with carefully trained observers, but it is an extremely difficult task for *S*. Most *Ss* do not feel very confident in the much simpler task of merely reporting the reversals that occur. Ideally we should be able to predict the minimum amount of prior satiation of one alternative required to cause the appearance of the other alternative first. With an adequate inspection figure this satiation time should approximate the normal duration of that alternative in *S*'s response to the reversible figure under the condition of no previous satiation. This length of time is of the order of only a few seconds or less, but if satiation induces the reversals, it normally has only that amount of time in which to build up. We should also be able to predict the absolute duration of each alternative after any given amount of prior satiation of one alternative. Until we can realize such predictions as these, we are not justified in assuming that satiation in Köhler's sense underlies the reversals in reversible-perspective and reversible figure-ground patterns.

The results with the old-woman-young-woman figure again agree with other findings with respect to the effects of satiation. According to Köhler and Wallach (6) and Köhler and Emery (5) the displacement satiation effects of one stimulus on another depend on differences in the spatial loci of the two. Since the two alternatives in the old-woman-young-woman figure do not differ even in apparent spatial relations, we should not expect prior satiation of one to affect that alternative differently from the other. The fact that the same alternative as the one previously satiated tended to occur first in *S*'s response to the reversible figure is interpreted as a suggestion effect. It could also be called an effect of expectancy or perseveration. Leeper (7), who used a similar modification of the same ambiguous figure but in a different experimental context, obtained results not incompatible with this general kind of interpretation. The important point is that this effect can be ruled out as an explanation for the results obtained with the ring figure.

In the writer's opinion Köhler's satiation hypothesis cannot be applied to the "reversal behavior" of meaningfully ambiguous figures without introducing basic changes in the concept of satiation as it has been developed in figural-aftereffect experiments. Whether such changes could be justified on theoretical grounds is much beyond the scope of this paper, but it may be pointed out that there is less necessity than might be expected for the same hypothesis to apply both to reversible-perspective and to meaningfully ambiguous figures. First, one can postulate a qualitative difference between the two. In a reversible-perspective figure the two perceptual alternatives refer to two different orientations of the same object. In a meaningfully ambiguous figure the two perceptual alternatives refer to two different objects, and no point in the figure changes its apparent spatial relation to any other point. Second, there seem to be behavioral differences. Most *Ss* will spontaneously experience the reversal in a reversible-perspective figure. Some coaching is usually required, however, before one can get many *Ss* to experience both of the perceptual possibilities in a meaningfully ambiguous figure. Even after *Ss* in the present study were well aware of the ambiguous nature of the young-woman-old-woman figure, the reversals occurred a good deal less regularly and rhythmically than was the case with the ring figure. All these differences between the two kinds of figure do not mean they have nothing in common, but any single principle need not necessarily apply to both.

Summary

Subjects were satiated on one alternative of a reversible perspective figure. Then their responses to the reversible figure were recorded over two cycles. The figure was used in two different orientations, designated RL and UD. In the RL orientation the two alternatives of response were "left" and "right." In the UD orientation the two alternatives were "up" and "down." The following results were obtained:

1. The *Ss*' ($N = 75$) first responses to the reversible figure tended reliably to be the alternative opposite to the satiated one.

2. The satiated alternative tended to last for a relatively shorter time than the nonsatiated alternative over the two cycles of *S*'s response to the reversible figure (based on a sep-

arate sample of 26 *Ss*). Although this effect was statistically significant for the UD data, it was not very clear-cut and consistent. In the RL data the same trend was evident, but the error variance was not distributed homogeneously, rendering the statistical test equivocal.

A repetition of both experiments with a meaningfully ambiguous figure indicated that the above effects were not due to a "suggestion" influence of some kind.

The results are interpreted as being in agreement with Köhler's hypothesis that satiation may underlie the reversals in certain reversible organizations. It is argued, however, that predictions are not yet precise enough for the hypothesis to be considered established.

(Received October 24, 1952)

References

1. Boring, E. G. A new ambiguous figure. *Amer. J. Psychol.*, 1930, **42**, 444–445.
2. Cochran, W. G. The comparison of percentages in matched samples. *Biometrika*, 1950, **37**, 256–266.
3. Hochberg, J. E. Figure-ground reversal as a function of visual satiation. *J. exp. Psychol.*, 1950, **40**, 682–686.
4. Köhler, W. *Dynamics in psychology*. New York: Liveright, 1940.
5. Köhler, W., & Emery, D. A. Figural aftereffects in the third dimension of visual space. *Amer. J. Psychol.*, 1947, **60**, 159–201.
6. Köhler, W., & Wallach, H. Figural aftereffects. An investigation of visual processes. *Proc. Amer. philos. Soc.*, 1944, **88**, 269–357.
7. Leeper, R. W. A study of a neglected portion of the field of learning—the development of sensory organization. *J. genet. Psychol.*, 1935, **46**, 41–75.

THE VISIBILITY OF A TARGET AS A FUNCTION OF ITS SPEED OF MOVEMENT[1]

W. T. POLLOCK[2]
The Johns Hopkins University

There are in the experimental literature a considerable number of research reports dealing with the perception of moving targets. Several of these concern the lower limen of movement, i.e., how fast a target has to move before movement can be perceived (see, for example, [3]). Others have reported data on the perception of relative, or differential, movement, i.e., how small a change in speed (acceleration) is just barely noticeable (see, for example, [4]). Still another kind of experiment (1) measured the accuracy with which *S*s could report the direction of target movement as a function of target luminance, speed, and size. All these experiments, however, used very limited ranges of target speed, in no case exceeding angular movements of 50° per sec. This means that the targets never exceeded speeds at which visual acuity is reduced virtually to zero.

If we now consider faster target speeds—speeds severely detrimental to visual acuity—we find very few experimental data. An early paper by DeSilva (2) summarized observations of *S*s who viewed slits of light moving at angular speeds from 3° to 116° per sec. At the top speeds, *S*s reported seeing a stationary sheet of light with no apparent direction of movement. A more recent pair of papers by Ludvigh (5, 6) gives data on visual acuity as a function of target speed. The targets he used were Snellen letters (first study) and Landolt rings (second study). His data show that visual acuity approaches zero when the target is moving at an angular speed of approximately 200° per sec. Similar results were obtained by Rose (7) using a different type of acuity target. These data tell us what happens to the *recognition* threshold as the speed of a target increases, but provide no information on the simple *detection* threshold of moving targets.

Purpose of this experiment.—It is possible to list several factors which might affect the detection threshold of a moving target. Stimulus variables such as speed, luminance, size, color, direction and extent of movement, luminance contrast, and others, are undoubtedly important. In addition to these target factors, such ocular factors as the region of the retina stimulated and the state of adaptation of the eye might well influence the detection threshold. This experiment, however, deals only with the monocular luminance threshold of a moving target as a function of the target speed and direction of movement.

METHOD

Apparatus.—The apparatus produced movement of a projected light spot at angular speeds from 0° to 2000° per sec. Figure 1 is a schematic drawing of its principal components. A con-

[1] This research was done in cooperation with the Systems Coordination Division, Naval Research Laboratory under Contract N5-ori-166, Task Order I, between the Office of Naval Research and The Johns Hopkins University. This is Report No. 166-I-165, Project Designation No. NR 507-470, under that contract.

[2] Based upon a thesis submitted to the Faculty of Philosophy, The Johns Hopkins University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The author wishes to express gratitude to his adviser, Dr. A. Chapanis, for assistance in carrying out this project.

FIG. 1. Schematic view of the apparatus: (*A*) Motor, (*B*) Speed reducer, (*C*) Prism, (*D*) Optical wedge and filters, (*E*) Shutter, (*F*) Aperture holder, (*G*) Projector, (*H*) Screen, (*I*) *S*'s chair, (*J*) Chin rest, (*K*) Viewing screen.

stant-speed motor (*A*) rotated a right-angle prism (*C*) at the desired speed through a continuously variable speed reducer (*B*). A cam surface on the base of the prism actuated a microswitch in circuit with *E*'s switch to control the shutter mechanism (*E*). The two switches controlled the operation of a release solenoid linked to the shutter mechanism. The opening of the shutter permitted a pencil of light from the projector (*G*) and aperture (*F*) to enter the prism. The moving prism reflected the light spot out to the viewing screen (*K*). The circuit controlling the shutter was so arranged that the shutter was open during only one revolution of the prism assembly. The entire assembly of motor, prism, and projector was mounted on a frame that pivoted on an axle. The axis of the pivot coincided with the center of the prism. A locking mechanism held the projection assembly in the desired angular orientation.

A screen (*H*) directly in front of the projection assembly permitted only the light spot from the prism through to *S*'s part of the experimental room. The *S*'s chair (*I*) in front of the screen was provided with a chin rest (*J*) that centered *S*'s head just below the projected light spot. The chin rest also positioned *S*'s eye 10 ft. from the viewing screen (*K*). The white viewing screen was rectangular in shape with the major axis curved to a radius of 10 ft. A small red fixation light was imbedded in the center of the screen. Black felt masks at each end of the screen restricted the visible travel of the projected target spot to 20° of visual angle at *S*'s position, i.e., 10° on both sides of the fixation spot. The center of the screen coincided with the central axis of the prism so that the projected spot always passed over the fixation light. The screen was supported in the rear by a shaft at its center which permitted rotation of the screen to any angular position.

The light source of the projection assembly was a 300-w. projection bulb housed in a 2-in. slide projector. The slide housing of the projector contained an aperture punched in brass shim stock which produced the circular test spot. When projected and focused on the viewing screen, the test spot subtended a visual angle of 1° at *S*'s position. The luminance of the test spot was controlled by an optical wedge and neutral density filters (*D*) located between the projector lenses and the right-angle prism.

The speed of movement of the 1° test spot was determined by the position of the control arm on the variable speed reducer. An electronic pulse timer activated by a cam on the base of the prism recorded the time required for single, complete revolutions of the prism. The control arm of the speed reducer was adjusted until the time per revolution of the prism associated with the desired target speed was obtained. For example, to get a target speed of 360° per sec., the

control arm of the speed reducer was adjusted until the pulse timer showed that the prism required 1 sec. to make a full revolution.

The direction of target movement on the viewing screen was varied by rotating both the projection assembly and the viewing screen about their centers.

Subjects.—Four college students, ranging from 19 to 25 years in age, served as *Ss*. All had uncorrected visual acuity of 20/20 or better as measured by a Snellen chart.

Procedure.—Eight target speeds and four directions of target movement were used. The eight target speeds were 50, 100, 200, 400, 800, 1200, 1600, and 2000 degrees of angular travel per sec. The directions of movement were right (from left to right on the viewing screen), left (from right to left), up (from bottom to top on screen), and down (from top to bottom). The combination of the eight speeds and four directions of movement resulted in a total of 32 experimental conditions.

Each *S* was tested on all 32 conditions. The conditions were presented in a counterbalanced order among *Ss* so that practice effects were distributed equally among all the conditions. During a given session, each *S* contributed thresholds to each of four of the conditions. Thus, eight sessions were required of each *S*. The conditions were arranged so that each *S* was tested on all four directions of target movement during each session. In addition, every target speed was presented during two successive sessions with a given *S*.

The *S* was dark adapted for 30 min. in the light-tight experimental room. After this adaptation period, *S* donned goggles which permitted vision in his right eye only. His monocular luminance threshold for each condition was obtained by the method of limits with six ascending and six descending series for each threshold. The moving light was presented at intervals of approximately 2 sec.[3] The *E* varied the target luminance during successive presentations by moving the optical wedge in .05 density steps. A short rest period was observed in the middle of each threshold determination and between each condition.

Threshold measurements for stationary targets, i.e., 0° speeds, were made with three of the *Ss* subsequent to the moving target measurements. These data were obtained in order to locate the speed threshold values on the luminance scale. Each *S* was tested with the stationary target 9° above, below, to the right of, and to the left of the fixation spot. An exposure time of approximately 1 sec. was used in the measurement of the thresholds. Otherwise, the procedure was the same as that used for threshold determinations involving the moving targets.

[3] Except for the 50° and 100° per sec. speeds at which the target was presented on each rotation of the prism. The resulting presentation intervals were 7.2 and 3.6 sec., respectively.

Results and Discussion

The results are presented in Table 1. Since no consistent differences were found between "up" and "down" directions of target movement, the thresholds for the two have been averaged to give "vertical" movement. Similarly, "right" and "left" thresholds were combined to give the "horizontal" data. The data for the 0° per sec. speeds were combined in the same way. These stationary targets gave threshold data which agree with data from other experiments using similar conditions (see, for example, [8]).

TABLE 1

Monocular Luminance Thresholds in Millimicrolamberts as a Function of Target Speed and Direction of Movement*

Direction of Movement	Speed (Degrees/sec.)	*Ss*			
		A	B	C	D
Vertical	0**	29	26	—	19
	50	119	123	135	81
	100	188	251	260	164
	200	386	570	401	214
	400	760	905	1170	428
	800	1460	1180	1550	649
	1200	1380	2360	2390	1300
	1600	2090	2150	4180	1360
	2000	2460	3700	4080	1760
Horizontal	0***	32	38	—	17
	50	116	175	196	69
	100	187	238	265	160
	200	377	696	572	223
	400	919	916	1540	364
	800	1240	2230	2130	888
	1200	1640	2700	3200	1190
	1600	2030	4170	3940	1680
	2000	2920	4060	5240	2100

* Each entry is based on 2 threshold determinations.
** Target stationary 9° above or below the fixation spot.
*** Target stationary 9° to the right of or to the left of the fixation spot.

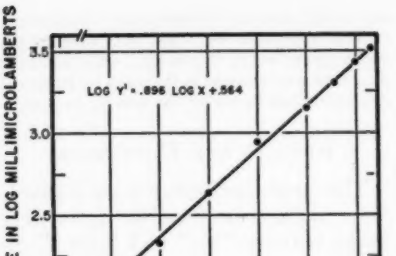

FIG. 2. Threshold luminance as a function of the speed of target movement. Each point is the average of 16 threshold determinations. The equation is that of the best-fitting straight line. Note that the speed scale is logarithmic.

Figure 2 shows the arithmetic means of the luminance thresholds as a function of target speed. Both the luminance scale and the speed scale are logarithmic. A linear function has been fitted to the data by the least-squares method although there is the suggestion of a break in the function at a target speed of approximately 400° per sec. This apparent discontinuity is discussed later.

That there is a consistent difference between the vertical-movement and the horizontal-movement thresholds is indicated in Fig. 3. At all speeds except one, the thresholds for vertical movement were lower than for horizontal movement. Evidence for the consistency of the differences is given by the near equality of the slopes of the fitted lines. Again, linear fits were applied to the data though some evidence of discontinuity is present.

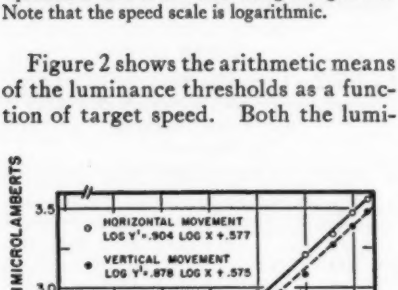

FIG. 3. Threshold luminance as a function of the speed of target movement. The parameter is direction of target movement. Each point is the average of eight threshold determinations. The equations are those of the best-fitting straight lines. Note that the speed scale is logarithmic.

TABLE 2

ANALYSIS OF VARIANCE OF THE THRESHOLDS IN TABLE 1*

Source of Variance	*df*	Estimated Population Variance
Between *Ss*	3	4,306,833***
Between speeds	7	11,301,337***
Between directions	1	1,042,186**
Interaction: *Ss* × Speeds	21	458,210****
Interaction: *Ss* × Directions	3	172,162
Interaction: Speeds × Directions	7	106,076
Residual	21	96,626
Total	63	—

* The 0° per sec. data were excluded.
** Significant at the 1% level.
*** Significant at the .1% level when tested against the interaction.
**** Significant at the .1% level.

Statistical evidence of the significance of the difference between directions of target movement is given by an analysis of variance of the threshold data in Table 1. The results of the analysis are given in Table 2. The data for the stationary targets were not included in the analysis since they were not part of the original experi-

mental design. This analysis shows differences between *Ss*, target speeds, and directions to be significant. Of special interest is the significance of the interaction of *Ss* and target speeds.

This interaction is no doubt a reflection of the differences in the shapes of the threshold functions of the individual *Ss*. The individual plots fall roughly into two classes. Two *Ss* gave functions which show a rather clear-cut break at a target speed of about 400° per sec., while the functions for the other *Ss* were more linear. It is interesting to note that target speeds of about 400° per sec. are associated with a threshold luminance of approximately 3.0 log millimicrolamberts. This luminance value is also associated with the rod-cone break in dark-adaptation curves. This might possibly explain the break in the threshold function found with two of the *Ss*. The explanation could be that threshold luminances with target speeds below 400° per sec. stimulate rods only while faster target speeds with higher threshold luminances stimulate both rods and cones.

An argument against such an interpretation is furnished by *Ss'* reports of the appearance of the moving spot. At all target speeds, *Ss* reported a foveal scotoma, i.e., they saw two bars of light—one on each side of the fixation point—with a dark area in the center. They reported exactly the same appearance of the stimulus even with slow target speeds and target luminances well above threshold.

It may also be of interest to report some other observations made about the appearance of the moving spot by *Ss* in this experiment. With target luminances well above threshold, none of the *Ss* was able to report the direction of target movement—whether up or down, or right or left—with any degree of certainty, except at the slowest speed of 50° per sec. However, even at that slow speed, *Ss* admitted that their judgments of direction of movement were based on the time difference in the appearance and disappearance of the target, not on the actual perception of target movement. These reports were obtained with fixation at the midpoint of the target excursion. The observations changed considerably when *S* was instructed to fixate so that the spot did not pass over the fovea. Under such viewing conditions, *Ss* reported direction of movement more accurately, absence of the foveal scotoma, and increased brightness of the target spot.

Other reports concerned the distribution of the apparent brightness of the moving spot. Increasing the speed of target movement produced reports of an apparent shrinking in the size of the spot as well as a decrease in its apparent brightness. Another observation concerned the appearance of the target path when it looked like two bars of light, i.e., with a foveal scotoma darkening the center of the path of the target. Each of the two bars appeared brighter at its center than at either end. This appearance was reported at all speeds of the target spot.

Summary

Monocular luminance thresholds of a 1° circular spot of white light were measured with the spot moving at angular speeds of 50–2000° per sec. The extent of target travel was 20° of visual angle with the midpoint of the target excursion centered on the fovea. The direction of target movement was either vertical or horizontal.

The results show that threshold luminance increases systematically with increases in target speed. The function is best characterized as linear with a slope near unity when threshold

luminance and speed are plotted logarithmically. However, there is some indication that the function relating target speed and visibility is not continuous.

The data show that vertical target movement yields consistently lower luminance thresholds than does horizontal movement.

(Received for early publication March 23, 1953)

References

1. Crook, M. N. Visual discrimination of movement. *J. Psychol.*, 1937, **3**, 541–558.
2. DeSilva, H. R. An analysis of the visual perception of movement. *Brit. J. Psychol.*, 1929, **19**, 268–305.
3. Gordon, D. A. The relation between the thresholds of form, motion, and displacement in parafoveal and peripheral vision at a scotopic level of illumination. *Amer. J. Psychol.*, 1947, **60**, 202–225.
4. Hick, W. E. The threshold for sudden changes in the velocity of a seen object. *Quart. J. exp. Psychol.*, 1950, **2**, 33–41.
5. Ludvigh, E. The visibility of moving objects. *Science*, 1948, **108**, 63–64.
6. Ludvigh, E. Visual acuity while one is viewing a moving object. *Arch. Ophthal., Chicago*, 1949, **42**, 14–22.
7. Rose, H. W. Visual acuity and angular speed of object. In Minutes and Proceedings of the 30th Meeting of the Armed Forces–NRC Vision Committee, April 1952, 77–79.
8. Sloan, L. L. Rate of dark adaptation and regional threshold gradient of the dark-adapted eye: physiologic and clinical studies. *Amer. J. Ophthal.*, 1947, **30**, 705–720.

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

The issues listed below are available for sale

Year	Volume	Available Numbers						Price per Number	Price per Volume
1916	1	1	2	3	4	5	6	$1.25	$7.00
1917	2	1	2	–	4	5	–	$1.25	$5.00
1920	3	–	2	3	4	5	6	$1.25	$6.25
1921	4	1	–	3	–	5	6	$1.25	$5.00
1922	5	–	–	3	4	5	–	$1.25	$3.75
1923	6	–	–	–	–	–	–	——	——
1924	7	1	2	–	–	5	–	$1.25	$3.75
1925	8	1	–	3	4	–	6	$1.25	$5.00
1926	9	–	2	3	–	5	6	$1.25	$5.00
1927	10	–	–	3	4	5	6	$1.25	$5.00
1928	11	1	2	3	4	5	6	$1.25	$7.00
1929	12	1	2	3	4	5	6	$1.25	$7.00
1930	13	1	2	3	4	5	6	$1.25	$7.00
1931	14	1	2	3	4	5	6	$1.25	$7.00
1932	15	1	2	3	4	5	6	$1.25	$7.00
1933	16	1	2	3	4	5	6	$1.25	$7.00
1934	17	1	2	3	4	5	6	$1.25	$7.00
1935	18	1	2	3	4	5	6	$1.25	$7.00
1936	19	1	2	3	4	5	6	$1.25	$7.00
1937	20	1	2	3	4	5	6	$1.25	$7.00
	21	1	2	3	4	5	6	$1.25	$7.00
1938	22	1	2	3	4	5	6	$1.25	$7.00
	23	1	2	3	4	5	6	$1.25	$7.00
1939	24	1	2	3	4	5	6	$1.25	$7.00
	25	1	2	3	4	5	6	$1.25	$7.00
1940	26	–	2	3	4	5	6	$1.25	$6.25
	27	1	2	3	–	5	–	$1.25	$5.00
1941	28	1	2	3	4	5	6	$1.25	$7.00
	29	1	2	3	4	5	6	$1.25	$7.00
1942	30	1	2	3	4	5	6	$1.25	$7.00
	31	1	2	3	4	5	6	$1.25	$7.00
1943	32	1	2	3	4	5	6	$1.25	$7.00
	33	1	2	3	4	5	6	$1.25	$7.00
1944	34	1	2	3	4	5	6	$1.25	$7.00
1945	35	1	2	3	4	5	6	$1.25	$7.00
1946	36	1	2	3	4	5	6	$1.25	$7.00
1947	37	1	2	3	4	5	6	$1.25	$7.00
1948	38	1	2	3	4	5	6	$1.25	$7.00
1949	39	1	2	3	4	5	6	$1.25	$7.00
1950	40	1	2	3	4	5	6	$1.25	$7.00
1951	41	1	2	3	4	5	6	$1.25	$7.00
	42	1	2	3	4	5	6	$1.25	$7.00
1952	43	1	2	3	4	5	6	$1.25	$7.00
	44	1	2	3	4	5	6	$1.25	$7.00
1953	45	By subscription, $15.00 (2 vols.)						$1.50	——
	46								

Information about the Journal of Experimental Psychology: as noted in the table, the journal was not published in 1918 and 1919; from 1937 to 1943 it was published at the rate of two volumes per year; from 1944 to 1950, in one volume per year. Beginning in 1951 there are two volumes a year.

Information about prices: when all numbers are available, the price per volume through 1952 is $7.00. Beginning in 1953, the price per volume is $7.50. For incomplete volumes, the price is $1.25 for each available number. For foreign postage, $.25 per volume should be added. The American Psychological Association gives the following discounts on orders for any one journal:

10% on orders of $ 50.00 and over
20% on orders of $100.00 and over
30% on orders of $150.00 and over

01665

Address orders and subscriptions to

AMERICAN PSYCHOLOGICAL ASSOCIATION

1333 Sixteenth Street N.W. Washington 6, D. C.